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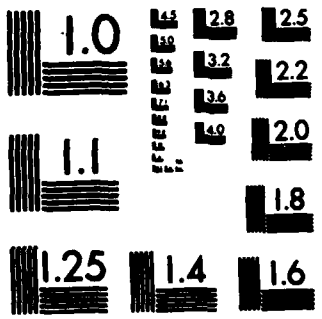

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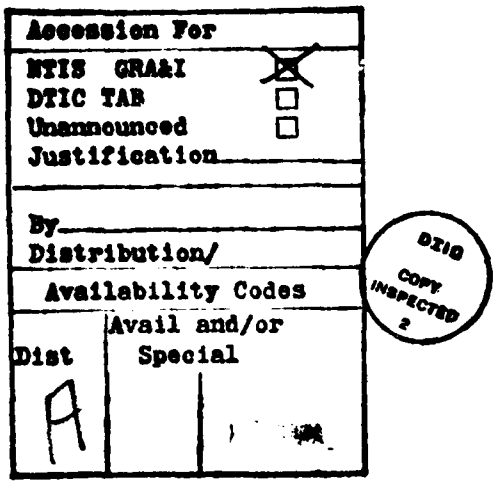

THE PERFORMANCE MEASUREMENT OF A RELATIONAL DATABASE SYSTEM USING MONITORING AND MODELING TECHNIQUES

THESIS

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THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University (ATC)
In Partial Fulfillment of the
Requirements of the Degree of
Master of Science

by

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Graduate Information Systems

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PREFACE

Relational databases are steadily moving toward the forefront of the management information arena. These databases carry with them many advantages over their existing predecessors, but one criticism seems to be continually associated with them - the excessive amount of time required to perform data retrieval.

Studies have been conducted to attempt to decrease the amount of time required by a relational database to perform a given retrieval. One of the more notable ones was undertaken by Dr. John Miles Smith while a faculty member at the University of Utah. Smith proposed several optimization techniques which, when applied to an existing parse tree of relational algebra operators, would theoretically decrease the amount of time required to perform the original query.

Shortly after these techniques were published, an Air Force Institute of Technology student, Lt. Mark Roth, began the development of a microprocessor-based pedagogical relational database, centering much of his effort on incorporating the Smith optimization techniques within his system design. This course of action was noteworthy, because while the optimization methods seemed productive, they had never actually been implemented in an operational database.

Dr. Thomas Hartrum, faculty member of the Electrical Engineering Department, suggested that the design and implementation of a software monitor which would analyze the effectiveness of these optimization techniques be undertaken as a master's degree thesis topic. I accepted this challenge, fully intending to complete the monitor and provide conclusive and informative results. However, due to the status of the actual implementation of the Roth database and insurmountable storage limitations encountered, experimental results were not obtainable. Instead, it was agreed that the monitor would be designed, coded, and tested, and that modeling the system using a high order simulation language would be explored as an alternative means of analysis.

This thesis effort has provided an exceptional learning opportunity for me. I have gained great insight into the fields of relational databases, microprocessors, and relational algebra query optimization techniques alike. Sincere gratitude goes forth to my advisor, Dr. Hartrum, as well as to my committee members, Dr. Henry Potoczny of the AFIT Mathematics Department and Major Michael Varrieur of the Engineering Department. Thanks also must be given to the AFIT/ENE technicians, especially Mr. Dan Zambon, for keeping the LSI-11 systems operational. Finally, deepest appreciation goes to my wife Linda and to my two children Chris and Kelly for their undying support.

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ABSTRACT

An investigation was conducted to provide a productive means of measuring the effectiveness of a collection of untested relational algebra query optimization techniques which are integrated within an existing microprocessor-resident relational database.

As a result of this research, two methods of performance measurement were proposed. A software monitor was designed, coded, and tested specifically to determine if the employed optimization methods actually decrease the amount of processing time required to execute a given query. Additionally, a baseline simulation model was designed and presented as an alternative means of analyzing the performance of this optimization logic.

THE PERFORMANCE MEASUREMENT OF A RELATIONAL DATABASE SYSTEM USING MONITORING AND MODELING TECHNIQUES

I INTRODUCTION

BACKGROUND

The computerized Management Information System (MIS) has evolved into an integral part of contemporary life; its effect on society as we know it is simply astounding. Nearly everyone is touched in one way or another by automated data management systems.

Until recently, a typical database was one of two types: either a "hierarchical" database or a "network" database, each drawing its name from the information structures and the means of data management employed. Then, in the late 1960's, E. F. Codd began working with a relatively new form of mathematics called "relational mathematics", consisting of "relational algebra" and "relational calculus". Relational mathematics permitted transactions on interrelated data by introducing a unique group of relational operators which could be used to manipulate these sets of information.

In the mid-1970's, a third type of computerized database was subsequently developed based on the

principles of relational mathematics, appropriately called the "relational database". Relational databases characteristically provide more simplicity, data independence, and human-friendliness than hierarchical or network databases. For these reasons, relational databases are often heralded as the "information systems of the future".

Although the relational database offers several advantages over hierarchical and network models, the management information community has expressed disapproval over one of its traits: current implementations of relational databases using existing architectures are slow and inefficient. Because data retrieval and manipulation is, after all, the underlying function of an information system, the speed and efficiency with which this data is managed is of utmost concern; thus the criticism of inefficiency levied on the relational database is a notable one.

In 1979, an Air Force Institute of Technology graduate student named Lt. Mark Roth set out to design, code, and implement a pedagogical relational database on a microcomputer system in the AFIT Digital Engineering Laboratory. Roth placed great emphasis on maximizing the data handling efficiency of his manipulation language; accordingly, he decided to incorporate two techniques in an attempt to improve data management performance. The first technique was inspired by a paper written by Theo Haerder

(Ref. 4). Haerder suggests combining a link structure which relates tuples of one relation to tuples of another to provide efficient retrieval with an image structure which gives ordering and associative access by attributes to provide efficient updates. Roth went on to discover that an image can be implemented and maintained through the use of a multipaged index structure containing pointers to the relation tuples. Furthermore, the pages of one of these indexes could be organized into a balanced structure using the concept of B*-trees (pronounced B-star).

The second technique Roth embodied in his database, and the one directly addressed by this thesis, may be described as an "automatic query optimizer interface", which logically resides between a user's set of relational algebra query commands and the data residing in the system. This interface, inspired by an article written by Dr. John Miles Smith and Philip Yen-Tang Chang in the 1975 Communications of the ACM (Ref. 11, hereafter referred to as the Smith & Chang article), takes any set of relational algebra commands entered by a database user, and optimizes them, such that no matter how inefficiently the original commands were constructed, they would be executed using the least amount of processing time possible. Consequently, it was hoped, even the most inexperienced database user would see results in the minimum required time.

Because of time constraints, much of the logic responsible for query optimization in the Roth database is

not yet operational. In addition, correspondence with Dr. John Miles Smith, the author of the paper upon which Roth's optimization techniques were based, indicates that these methods were only attempted in one other Data Base Management System, and that project was subsequently abandoned. Consequently, it appears, this specific effort at improving the underlying problem of relational database inefficiency is still largely conceptual.

Due to the untested nature of these optimization ideas, a fundamental question immediately arises. It is not known if these optimization techniques really optimize. It is conceivable that more overhead is required to optimize than would have been required to execute certain types of initial command files; i.e., obvious situations may exist (characterized by specific command file size, operator type mix, relation sizes, number of relations involved, etc.) for which the execution of optimization logic is counterproductive. Because of the interest currently placed on relational databases, attempts at improving execution speed will become increasingly important. Query optimization at the conceptual level is a strong contender as a primary means of achieving this improvement; thus answers to the questions raised against the Roth database could prove beneficial to database designers for years to come.

As the Roth database system approaches completion, there are two apparent means of determining how

successfully it is performing; i.e., determining whether the optimization techniques are of merit and whether there are any other possible areas of inefficiency which could be improved. One method of evaluation would be to model the execution of the Data Manipulation Language. By using a system modeling technique, one could represent the Roth optimization logic as an operational data manipulation system. Various parametric changes could subsequently point out the effect that different structures, e.g., command file size, operator mix, etc., have on overall execution time. By employing existing simulation language capabilities, the time duration of key PASCAL procedures could be modeled as functions of critical Roth database characteristics.

A system model can either be a simulation model or an analytic model. A simulation model reproduces the behavior of the system, in turn establishing a correspondence between the model and the system itself. Simulation models are characterized by states, or the values of given system parameters at a specified time, t, and transitions, the variations of parameter values from state to state. These state transitions are commonly referred to as events, and a system which evolves from predominantly discontinuous events is called a discrete event system. While a system can be simulated using any computer language, including PASCAL, numerous simulation languages specifically designed to model system events currently exist, such as SLAM,

SLAMII, QGERT, and SCERT. SLAMII, developed by Pritsker and Associates (Ref. 13) and supported by AFIT resources, provides an excellent capability for modeling the Roth optimization logic.

In addition to simulation models, a system may be represented as a series of mathematical equations. Such a model is called an analytic model. An analytic model may be one of two types, depending on the characteristics of its parameters. If all system variables are predetermined, the model is deterministic; if at least one system variable is random, the model is probabilistic. Probabalistic models are commonly either queueing models, in which a system is represented as queues and activities fed by these queues, or Markov models, which specifies statistical relationships between states in the form of a transition-probability matrix. Analytic techniques are sometimes combined with simulation methods to provide a hybrid model.

In addition to modeling, a second means of determining how efficiently the Roth database is performing involves physical monitoring which actually measures execution times. Transactions may be measured by using one of three types of measurement tools: hardware tools, software tools, or firmware tools. In addition, a system may be monitored by using a combination of hardware and software called a hybrid tool (Ref. 2, p. 31). A hardware monitor detects transactions by detecting pulse changes or bit patterns at the machine level. A firmware monitor, on

the other hand, relies on microcode added to the system firmware to detect specific branch conditions, use of predetermined opcodes, etc.

Unlike the hardware or firmware monitors, the software monitor consists of additional logic integrated into existing operating system or applications routines which detects transactions as they occur. Incorporation of a software monitor within the Roth optimization logic would assist a user in identifying logical deficiencies which may seriously hamper data manipulation efficiency. A software monitor would provide a means of determining the amount of time required to optimize queries, as well as the amount of time needed to execute a command file. Once the monitor is installed, experimentation with various types of queries could provide valuable information indicating what kinds of queries are enhanced by optimization logic, and what kinds are not. Additionally, the monitor could be extended to other areas of the database logic in order to disclose additional user-required information which would depict candidate erroneous or inefficient code.

Literature review indicates that few relational information systems contain the facilities to collect performance data; however, in the mid-1970's two employees of the General Motors Corporation , N. Oliver and J. Joyce, implemented a software performance monitor in their REGIS relational database (Ref. 12). Oliver and Joyce

point out that the function of the monitor was to collect data pertaining to the usefulness of the command language, monitor performance improvements following system enhancements, and make performance predictions based on past runs. They employed existing modules within the package to gather and store data, producing standard output tables which contained their results. Oliver and Joyce contend that REGIS users gained nearly an order of magnitude improvement as a result of correcting some of the problems discovered by using the performance monitor.

STATEMENT OF PROBLEM

The purpose of this thesis is to survey computer performance techniques applicable to database management systems and to develop and implement practical methods which will permit the analysis of the performance efficiency of the Roth Relational Database optimization modules. The Roth database DML is written in PASCAL, and the database itself currently resides on the LSI-11 microcomputer system located in the Air Force Institute of Technology Digital Laboratory. The performance analysis specifically focuses on the merit and applicability of the query optimization techniques of the Roth logic.

GENERAL APPROACH

The first step of this effort consisted of an extensive literature review which focused on three areas.

The first was information on existing database performance monitors, specifically any implemented on relational databases. The second area of literary interest was an in-depth study of the Roth thesis and a thorough examination of the Smith & Chang paper upon which the Roth optimization techniques were based. The third area of research centered around a study of the SLAMII simulation language developed by Pritsger and Pegden, subsequently used to model the Roth database logic.

Realizing that performance evaluation was the underlying goal of the project, the next step was to determine how to make the evaluation. The development of a performance monitor seemed to be a viable means of system evaluation. A significant drawback of this method, however, was the fact that the Roth logic was not yet and may not soon be totally operational. In addition, severe system resource limitations were causing operational difficulties. As a result, the design and coding of a monitor seemed practical within the timeframe allowed to complete this thesis; total implementation, howevever, was doubtful. Consequently, a second means of evaluation, which would not require that the Roth database be fully operational, appeared to be worth investigating; i.e., model the Roth manipulation language in order to make performance predictions based on variable system parameters. It was further determined that the most effective means of modeling the system would be a

simulation model, since a simulation allows system behavior observation over time, under stimuli generated to represent system inputs, yielding numerical results which may be used in system analysis. In addition, SLAMII was chosen as the simulation language representing the system because of its discrete event/network capabilities, its user-function capabilities which would permit execution durations to be easily represented as functions of system parameters, and the availability of SLAMII support at AFIT.

SCOPE

The development of a completely detailed modeling network which would successfully evaluate system performance would be a highly formidable task. Similarly, the design, coding, and implementation of a software performance monitor which could be integrated with the existing Roth database manipulation language, would also be a considerable assignment within the time constraints allowed for this thesis effort. As a result, the goal of this thesis is to completely design and code the software performance monitor and implement the design as much as possible depending on the operational status of the database itself at the time the monitor is ready to be incorporated. In addition, a baseline model of the Roth query optimization logic which will address the structure and parameters required to experimentally simulate the Roth logic will be designed and discussed in detail.

SEQUENCE OF PRESENTATION

The remainder of this thesis consists of six chapters. Chapter II is an overview and analysis of the Roth database, primarily focusing on the optimization techniques utilized to attempt to minimize the time required to perform user queries. Chapter II also summarizes the techniques discussed in the Smith & Chang paper, and addresses the similarities and differences between the two works. It also briefly reviews the optimization techniques used to represent tuple index pages as nodes of B*-trees.

Chapter III is a requirements description chapter which addresses those criteria which must be evaluated. It primarily depicts the relative advantages of monitoring vs. modeling, and what information needs to be captured from the Roth database logic in order to provide an effective performance evaluation.

The goals and design of the actual performance monitor are presented in Chapter IV. The overall purpose and general approach toward accomplishing the software monitor objectives are expounded upon.

In contrast, Chapter V describes the methodology behind modeling the optimization logic of the Roth DML. An overview of simulation modeling using the SLAMII modeling language is provided. A baseline SLAMII diagram depicting the Roth optimization logic is included as Appendix A of

the thesis.

Finally, Chapter VI summarizes the thesis effort and provides recommendations for follow-on tasking.

II OVERVIEW OF THE ROTH OPTIMIZATION LOGIC

BACKGROUND

The Roth relational database was created to satisfy the need for a good pedagogical tool in the relational database area. Roth initially hoped to have the system completely operational at the conclusion of his effort. As he got further into his work, however, he became aware of the emphasis which needed to be placed on query efficiency, both in terms of time and space; as a result, Roth was only able to create the front end of the system.

The Roth relational database was designed to achieve as near optimal behavior as possible, while being implemented as a general purpose system to be used as a pedagogical tool for teaching database management and manipulation. The system was designed using a top-down structured approach, and consists of four basic modules:

SETUP	initialization/logon
DDL PROCESSOR	domain/relation definition
DML PROCESSOR	data manipulation/retrieval
SHUTDOWN	definition/relation storage

The Roth Database design places great emphasis on query optimization at the conceptual level, and was strongly influenced by the Smith & Chang article, which addressed the design of an automatic interface capable of optimizing a given set of user relational algebra query commands. In agreement with the article, Roth makes the following points concerning query optimization:

1. Relational database systems provide users with tabular views of data. Consequently, users often create highly inefficient queries. Roth contends that "the burden of efficiency, since effectively removed from the user, must be assumed by the interface to the database".

2. Very significant optimization can be done at higher levels of interpretation where the global structure of a query is known.

3. Relational algebra was used to develop the interface because "a relational algebra treats and manipulates whole relations as single objects...a relational algebra may be considered at a higher level of abstraction than other interface systems, and thus offer more scope for high level optimization" and "if a relational algebra is conducive to smart optimization, it might provide a practical implementation level for other query languages."

The Roth optimization logic attempts to optimize a

given user relational algebra command file in two ways. First, it builds an operator parse tree in which each node corresponds to a single operator of the command file. After the tree is built, it is physically rearranged to decrease the time required to perform subsequent retrievals. Second, the partially optimized command tree is analyzed in terms of temporary relations which are to be created. The tuples of these relations are then preordered to enhance any searching activity required to actually process the data.

Roth's query optimizer appears in the EXECUTE logic of the RETRIEVE module, a subset of the DATA MANIPULATION PROCESSOR(Ref. Figure 1). The optimization code itself is further divided into four submodules: TREE, SPLITUP, OPTIMIZE, and RUN. Together, these four modules perform six basic functions which transform a user command file into an optimized set of coordinated concurrent tasks. Briefly stated, these six functions are:

1. Apply transformations to the original packet.
2. Achieve maximum concurrency.
3. Determine interface conventions.
4. Implement each task.
5. Evaluate decision effects.
6. Implement new task generations.

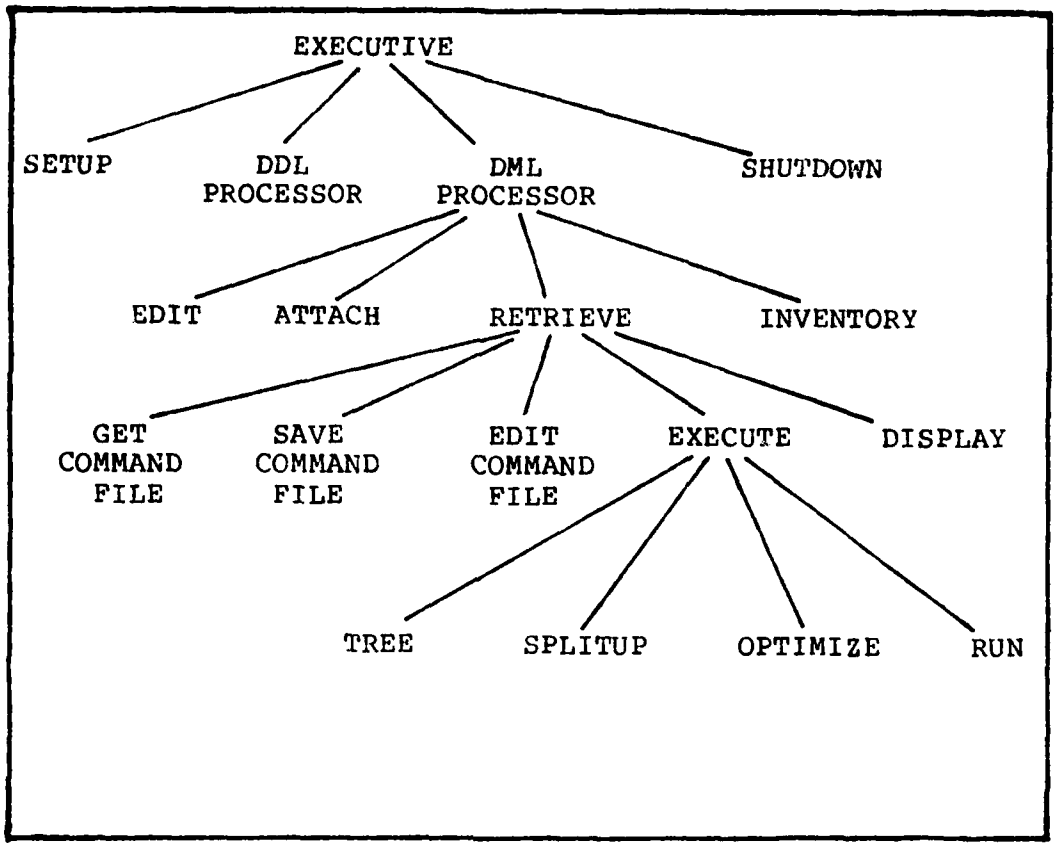

Figure 1. Roth Relational Database System Design

OPTIMIZATION MODULES

The Roth optimization logic begins with TREE and terminates with RUN. Graphically, the execution is represented in Figure 2.

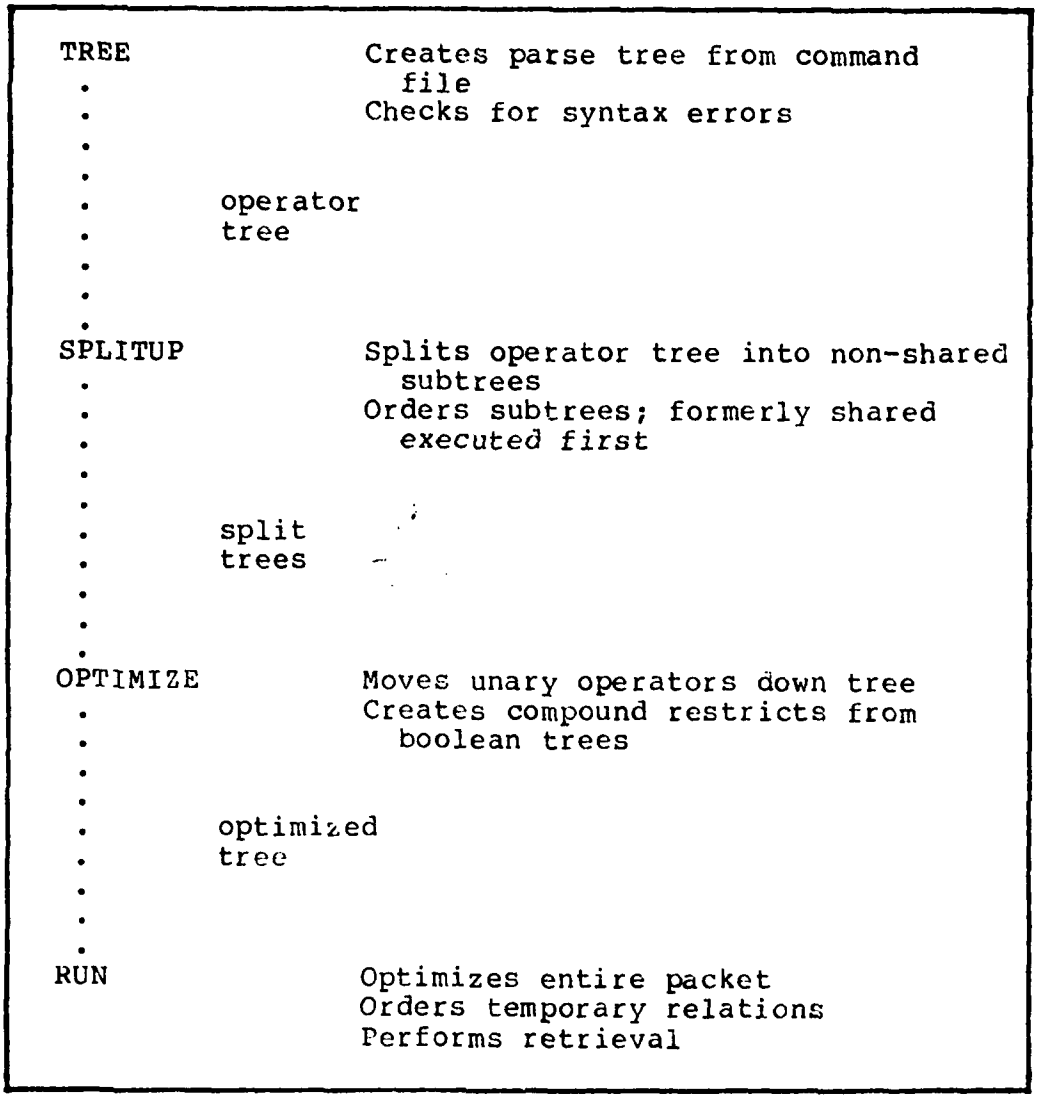

Figure 2. Roth Optimization Modules

These modules closely parallel those presented in the Smith & Chang design (called SQUIRAL) depicted in Figure 3.

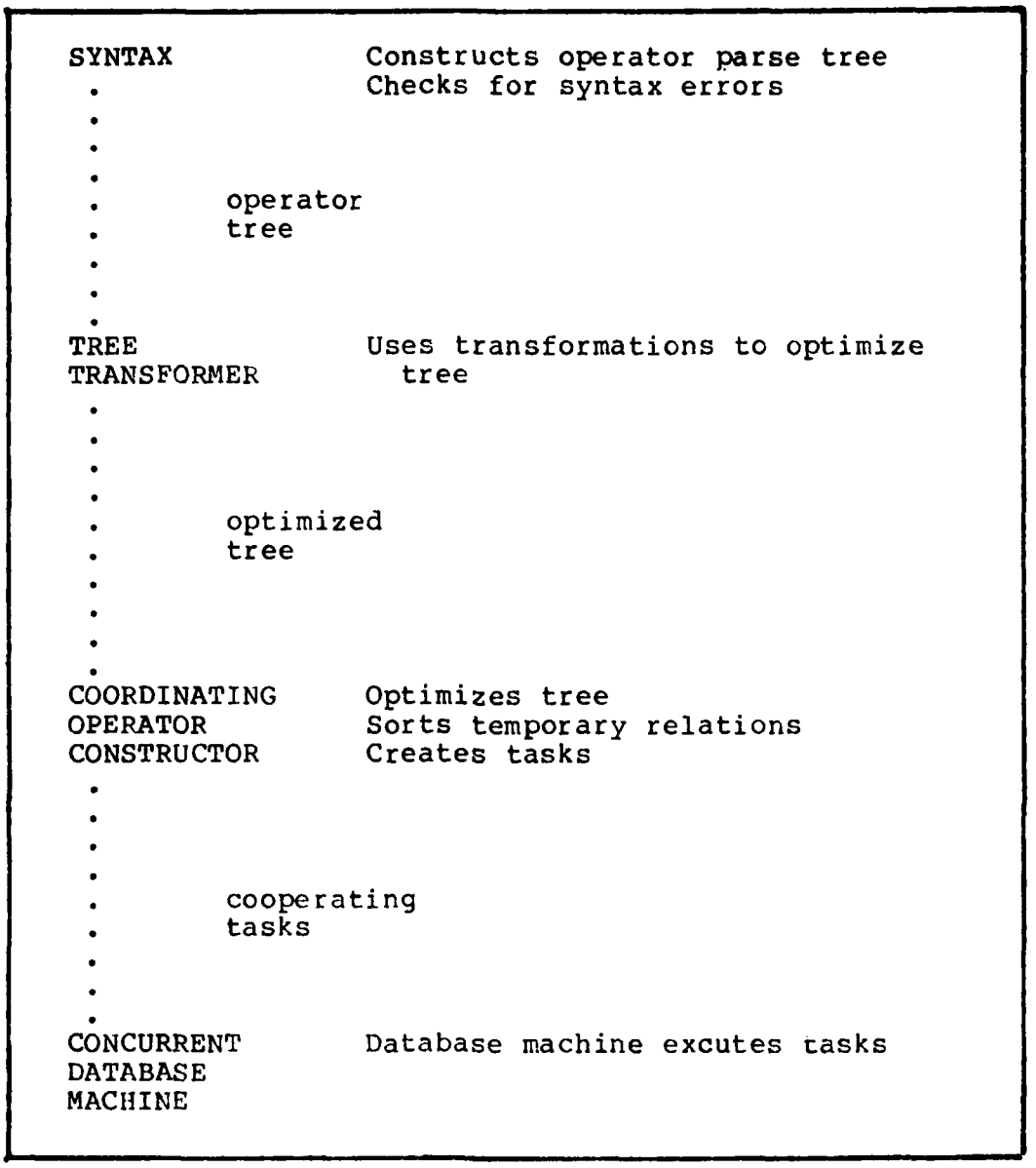

Figure 3. SQUIRAL Optimization Modules

After TREE examines the user command file and creates an operator tree, SPLITUP begins dealing directly with

optimization; specifically, it serves as a prelude to OPTIMIZE by taking a network of shared subtrees created by TREE, splitting this network into a series of non-shared subtrees, then chaining these individual trees together, ordering them from most-used to least-used. The result is a series of trees, some of which were formerly shared subtrees, ordered such that an intermediate relation is created before its results are required by subsequent subtrees. This results in a formerly shared subtree being executed only once, and works for shared subtrees which occurred in different queries as well as the same query.

The OPTIMIZE module, as the name implies, is responsible for the bulk of the query optimization performed by the Roth database DML. OPTIMIZE evaluates and modifies the chain of individual trees output by SPLITUP using three basic types of correctness preserving tree transformations. These transformations are performed by the following three logic modules:

1. COMBOOL. The function of COMBOOL is to convert a specific type of operator subtree, called a "boolean tree", into a single operation having a single compound boolean predicate. Direct boolean tree implementation requires that a single input relation be read multiple times. The transformation of a boolean tree into a single operation permits the same transaction to take place, with the input relation being read only once.

2. SELDOWN/PROJDOWN. These two algorithms are responsible for "pushing" SELECT and PROJECT nodes down the operator tree. It is especially productive to push SELECTS as far down the tree as possible, because the further down the SELECT operator resides, the greater the number of unused tuples which can be eliminated from the temporary input relations. It is also advantageous to move PROJECT operators down the tree, since they decrease the width of tuples and can lead to the elimination of tuples from relations. Some consideration must be given to the location of PROJECT operators, however, because the implementation of PROJECT operators does not make use of directories, and pushing a PROJECT past an operator which can, such as a JOIN, eliminates the capability of using directory access.

3. SIMSEL. The SIMSEL module is responsible for transforming a compound boolean predicate on a SELECT operator into conjunctive normal form, and simplifying the result.

The final optimizing module of the Roth database is the RUN module. The RUN module employs an algorithm implemented by another AFIT student, Lt. Peter Raeth, called CORC, the Coordinating Operator Constructor (Ref. 18). Once the operator trees have been built(TREE) and optimized(OPTIMIZE), the nodes must be executed in order to perform the retrieval operation. The CORC logic considers

the fact that prior to execution of an operator tree, execution speed would improve if attention were paid to the order of tuples within a relation before that relation is passed up the tree for subsequent processing. Restated, operators can perform more optimally if the relations upon which they are acting are presorted on the attributes which that particular operation is interested in. This tuple sorting is accomplished by the CORC logic using three passes through the tree:

1. PASS 1 (up). Domain fields resulting from the node's operator are attached to the node. The sort order of base relations is attached to the applicable nodes.

2. PASS 2 (up). Each node is labelled to indicate what preferred sort orders (PSO's) are available from the node below.

3. PASS 3 (down). One of (possibly) many PSO's are chosen from the node below and compared to the sort order subsequently required, to effectively determine the implementation of that node.

It is obvious that the activity resulting from the three CORC passes is based on a series of logical

decisions dictating which particular sort order is preferred and what operator implementation is to be used for a given situation. These decisions are made based on a table (Ref. 17, p. 41-42 and Ref. 18, p. 574-575) of UP-rules and DOWN-rules introduced in the Smith & Chang article which dictate which domain should be sorted to enhance subsequent processing as well as what specific type of implementation each operator should adhere to (Ref. 17, Appendix C and Ref. 18, p. 577-579).

SUMMARY

The Roth optimization logic strongly resembles the SQUIRAL design presented in the Smith & Chang article, although some significant variation is noticeable. SQUIRAL strictly addresses single queries; i.e., the user formulates a single query and expects a single relation as a result. Roth's database not only considers single queries, but extends these concepts to provide simultaneous optimization of a set of queries. Roth further contends that this may be done by the "exploitation of shared subtrees not only within a single query but also among different queries, and in the execution order of the various queries." It was because of this enhancement that the SPLITUP module was added to the Roth design.

Because of the untested nature of SQUIRAL and the non-operational status of the Roth data manipulation language, the merit of the optimization logic is still questionable.

It is conceivable that the Roth optimization modules do not optimize at all, or, more likely, there may be instances in which the optimizer overhead exceeds the time and resources required to execute the original command file. Smith & Chang conclude their article by commenting, "There is of course time overhead associated with automatic programming. However, since a complex query over a large database might take several hours to produce an answer, the time spent in analyzing a small operator tree is insignificant." It is reasonable to assume from this statement that if the optimization techniques work at all, they are geared toward complex queries, and may not significantly improve retrieval efficiency for the majority of applications.

III RELATIONAL DBMS PERFORMANCE ANALYSIS: REQUIREMENTS

OVERVIEW

Performance evaluation is essential to all areas of engineering. Before any new system is marketable, it must adhere to certain preassigned performance specifications. In addition, evaluation techniques can often be applied to existing systems, either to provide decision making criteria such as whether to purchase the system, or to indicate existing substandard areas requiring improvement.

Two things are generally considered when determining system performance. First, a given system must perform its functions correctly. Second, the system must perform its functions efficiently; it must complete its defined tasks within user- prescribed time and space restrictions. Performance analysis is especially concerned with the second consideration, how efficiently the system carries out its predetermined tasks.

Assuming the management system correctly manipulates data, the amount of time and storage space required to do so become the two critical database management performance issues. Since the underlying purpose of a database management system is to store and retrieve data, it naturally becomes important just how quickly this

information can actually be manipulated. Similarly, much interest exists in adapting management systems to microprocessors, in turn creating a need for more efficient use of primary and secondary storage capabilities.

As summarized in Chapter II, the Roth DBMS focuses on execution time optimization by invoking certain relational algebra query techniques which could be of interest to the entire relational database community. More and more emphasis is being placed on decreasing the amount of time required to retrieve data from a relational system. The underlying problem with the optimization concepts Roth employs is that they are virtually untested. Even assuming that these methods do not interfere with the correctness of execution of the retrieval function of the data manipulation language, it is still questionable how much retrieval time is saved by using these optimization principles.

The purpose of this thesis effort is to analyze the impact of the optimization techniques employed by the Roth database system upon the overall execution time required to process a relational algebra query. The following questions need to be addressed:

1. Do the relational algebra optimization techniques employed by the Roth data manipulation logic actually decrease processing time while preserving correctness?

2. Assuming these methods do improve execution time in some instances, are they effective for all cases? Are there certain system characteristics which could easily be identified for which the overhead inherent within the techniques outweighs the advantages of optimizing? Examples of these parameters are:

Command file size

Command file mix

Number of temporary relations created

Size of relations

3. Assuming that the Roth optimization techniques are beneficial in some instances but not in others, are there obvious suggested modifications to the system which could take advantage of these observations in an attempt to achieve further optimality?

PERFORMANCE MEASUREMENT

The overall goal of this thesis and any follow- on to this effort is to evaluate the efficiency of the Roth data manipulation language by comparing the execution times of both optimized and non-optimized data manipulation language. In order to accomplish this task, two things must be considered. First, an experimental set of benchmark

command files must be created which would provide a representative cross-section of requirements to be placed on the system. The second consideration is determining at what points to take the measurements in order to reflect the amount of execution time required to process the commands.

In order to measure the effectiveness of the Roth optimization techniques, a set of benchmark queries and test relations must be created designed specifically to determine whether the optimization modules are satisfying their objectives. Five benchmark queries have been developed which test the optimization techniques employed by the Roth data manipulation language. These queries are pesented in Appendix B along with a table of relations constituting a test data base against which these command files may be run.

In his thesis (Ref. 17, p. 55), Roth points out that "Previous attempts at optimization have considered only single expressions. That is the user formulates a single query and expects a single relation as a result. This thesis has expanded this viewpoint to include multiple queries for which the user expects several relations as the result. Thus the opportunity exists for simultaneous optimization of a set of queries. These opportunities occur in two areas: in the exploitation of shared subtrees not only within a query but also among different queries, and in the execution order of the various queries. These

ideas are embodied in the module SPLITUP."

Query 1 has been designed to exercise the SPLITUP logic. Query 1 actually consists of three command files which employ shared subtrees while attempting to provide three unique results. As addressed later in this chapter, the SPLITUP optimization techniques could be evaluated by measuring overall system execution time while running this multiple query with and without executing the SPLITUP module.

A second optimization technique employed by the Roth logic (specifically the SELDOWN and PROJDOWN algorithms) involves moving SELECT and PROJECT operators as far down the operator tree as feasible in order to eliminate needless data as early during processing as possible (Ref. 17, p.62). If a query consisted exclusively of SELECT and PROJECT operators, it would seem unnecessary to execute the SELDOWN and PROJDOWN algorithms, since SELECT and PROJECT operators would already be at the bottom of the tree.

Query 2 is an example of a query which consists solely of SELECT and PROJECT operators. A good test of the SELDOWN and PROJDOWN techniques would be to measure the total system time required to process this command file with and without executing these two algorithms.

Probably more common than a query which consists entirely of SELECTS and PROJECTS, is a query which could also eliminate the need for the SELDOWN and PROJDOWN

algorithms by naturally placing SELECT and PROJECT operators at the beginning of the file, effectively inserting them at the bottom of the corresponding operator tree. Query 3 is an example of this type of command file.

Another optimization technique employed by the Roth database is implemented in the COMBOOL algorithm (Ref. 17, p. 58). COMBOOL works on the principle that improved efficiency may be obtained by transforming certain operator trees, or subsets of operator trees called "boolean subtrees" which read a given relation from diskette more than one time, into a single operator which reads the relation only one time. Query 4 is an example of a command file which when directly implemented provides an operator tree identical to the example appearing in the Roth thesis (Ref. 17, Fig. 12); i.e, the operator tree corresponding to the existing command file already contains a boolean subtree. An interesting test of the COMBOOL optimization technique would therefore be to measure the execution time of this file using the existing Roth logic, and then to measure the execution time of the same query while bypassing the COMBOOL procedure.

Query 5 is designed to analyze the efficiency of the Roth logic attempting to optimize an already optimal command file. Within the EXECUTE procedure, which serves as a driver during the optimization processing, a copy of the optimized operator tree is printed to the terminal using the PRINTEE procedure. A valid test of execution

time efficiency would be to measure the processing of Query 5, a highly inefficient command file, from beginning of execution through completion of the RUN module, and then, using the PRINTREE output, to measure the same processing interval using the optimized version of the query. This test would reveal what consideration is given to an already optimal command file.

Operationally, the user action required to exercise a query against the Roth database begins with the DDL processor, at which time the domain and relation definitions are created. Once this task has been accomplished, the DML processor is used to enter the RETRIEVE module of the logic. The user is required to GET the command text file which contains the database query, and EXECUTE it. Upon the completion of the EXECUTE module, the results of the query are DISPLAYed.

Except for the EXECUTE logic, the efficiency of processing within the Roth database is dependent upon user keyboard interaction; as a result, measuring execution speed would be inconclusive. In addition, the optimization techniques reviewed in Chapter II appear within the EXECUTE module. For these reasons, measurement of the time required by EXECUTE to process a query is the critical performance analysis requirement.

The points of performance measurement within the EXECUTE module may effectively be represented hierarchically. Figure 4 examines the first level of

measurement to be taken. Case I, which utilizes the optimization logic, performs measurements within the EXECUTE driver, immediately prior to the call to tree and immediately following the call to RUN. Conversely, case II

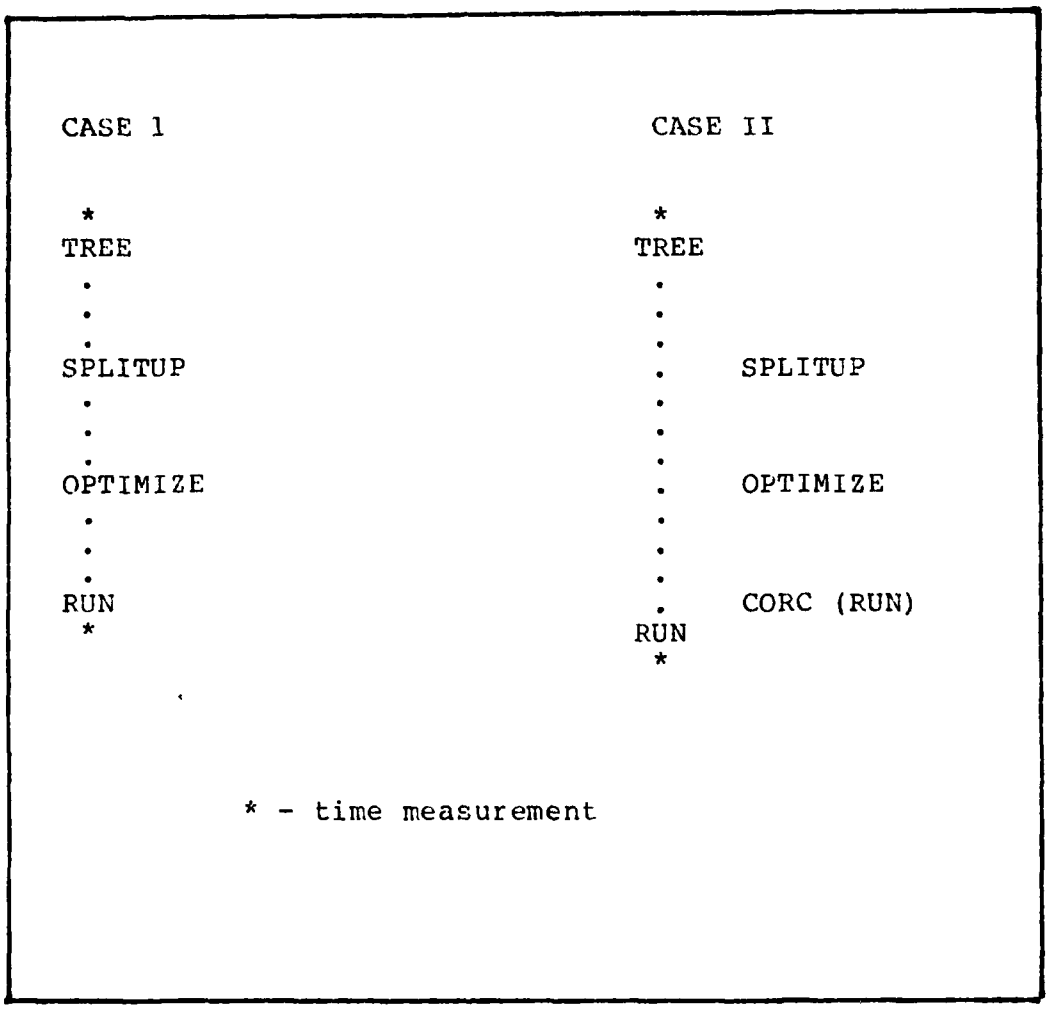

Figure 4. Performance Measurement
Level 1

shows bypassing the SPLITUP and OPTIMIZE modules along with the optimization portion of the RUN module, while taking a measurement before the TREE module and after the execution of the RUN module. By exercising the database using the benchmark set of queries, it may be determined for which types of queries the optimization techniques are productive.

After the overall execution times of the optimized and non- optimized logic have been analyzed, it would be interesting to measure the execution times of individual areas of logic. If, for example, it was determined that optimization was counter- productive for a query which contained a large percentage of SELECT operators, the amount of processing time required within individual optimization modules could provide insight into overall system execution. Measurement Level II, depicted in Figure 5, permits time measurement of individual optimization modules. Measurements are taken upon entering TREE, exiting TREE, entering SPLITUP, exiting SPLITUP, entering OPTIMIZE, exiting OPTIMIZE, entering RUN, exiting the CORC algorithm of RUN, and exiting the RUN module itself.

The optimization methods which appear within the Coordinating Operator Constructor of the RUN module

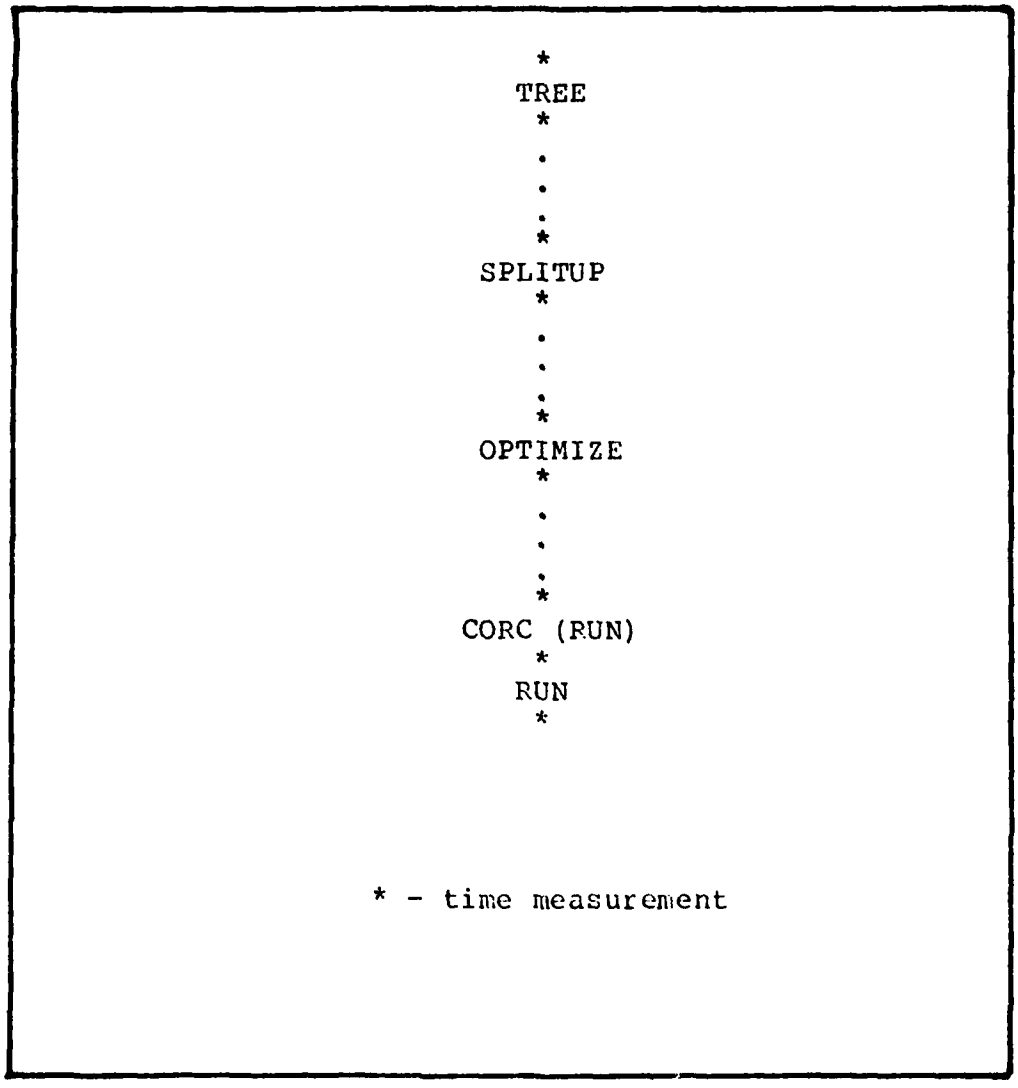

Figure 5. Performance measurement
LEVEL II

provide the area of interest addressed by Level III of the performance measurement hierarchy. As presented in Chapter II, the CORC logic takes the relational algebra operator tree and implements each node using a set of basic procedures such that the sort orders of intermediate relations are optimally coordinated. At this point in time,

the rules applied to coordinate these sort orders are purely heuristic and untested. Level III offers an opportunity to experimentally validate the basic procedures employed by the CORC logic.

The most straightforward means of measuring the effectiveness of the choice of coordinating procedures used by RUN is to simply determine the amount of time required to process RUN while methodically altering the techniques used to sort the relations and choose various operator implementations. For instance, using an example from the Roth thesis (Ref. 17, p73-74), the statement is made, "The UP-rule for JOIN (R[C=D]S), where one operand (R) is at a leaf and the other (S) is internal, indicates that if S is unary and a directory exists for the joining domain (C) of R then the preferred output sort order is dR. In this case dR = S# and C = S#, and so the output of JOIN is labeled with {S#}." In this example, dR and C are equal, but if C had some other value, say P# (part number), the fact that the JOIN output would still have been labeled with {S#} would have been significant. By measuring the execution time of RUN while changing the output of JOIN to {P#} could provide an indication of the correctness of this particular UP- rule. Similar experiments should be performed to demonstrate the validity of the CORC sort order and implementation rules.

Another area of performance within the Roth database system which requires analysis appears outside of the query

optimization logic. Roth proposed a data access structure to retrieve and modify stored data which was based on a structure introduced by Theo Haerder (Ref. 4). Haerder's structure allows immediate information retrieval without examining unwanted data in the process. It combines the advantages of pointer chain and multilevel indexing techniques by using a B*-tree general access structure, with a B*-tree constructed for each domain.

The initial Roth design called for the addition of a B*- tree pointer to each domain and having each B*-tree structure reside in main memory. When the system was non-operational, all of this information was disk resident, and when the database was executed, the data was automatically read into memory and dynamically constructed using Pascal pointers and data structures. Unfortunately, this proposal became impractical due to memory constraints. As a result, the current implementation stores each B*-tree structure on disk, and swaps the structures or parts of the structures in and out of memory as required.

The current access structure implementation raises two performance questions which must be answered. The first question was brought out in a follow-on to the Roth effort written by Lt. James D. Mau (Ref. 8, p. 62). Mau decided that "Each level of the B*-tree will be limited to three non-leaf nodes and the height of the B*-tree will be limitless. The best choice of these parameters is

a performance tradeoff that will require further study.". The issue here is to determine which structure will permit the fastest retrieval while still remaining within primary memory constraints, a tree with large nodes but few levels or a tree with small nodes but many levels. A performance measurement from the time an access is initiated to the time data is made available would assist in answering this question.

The second performance question involving data structures arises when a leaf node becomes full. When a B*-tree leaf node becomes full, a reorganization of the tree is required in order to accomodate the next entry to be placed into that node. In addition, there are several methods of tree reorganization from which to choose, in turn raising the question of optimality. Effective use of performance measurements could once again assist in determining which of these insertion techniques should be employed.

MONITORING vs MODELING

In order to evaluate the performance of any kind of system, pertinent information has to be gathered. To effectively evaluate the performance of the Roth database data manipulation language, this performance measurement data may be collected in one of two ways: from the system itself (monitoring), or from a model of the actual system (modeling).

Performance measurement through the use of a software monitor provides the capability of actually observing the times required to execute the optimization modules of the Roth database. The most straightforward means of implementing a software monitor is through the insertion of software probes, providing a trace of those instances a given subset of logic is entered. There are notable advantages to monitoring the Roth DML:

1. Accuracy. A monitor measures the performance of actual code. Since this process is somewhat mechanical, the evaluator can be confident that the true optimization process is being analyzed.

2. Easy to interpret. Since monitoring provides the capability of observing execution, evaluation may be performed simply by analyzing a trace to determine how much time was required to perform a given module of code.

In general terms, software monitors are specialized sets of code which collect information about activities caused by the execution of particular programs or sets of programs. Software monitors were probably the first tools developed to examine the performance of computer logic, and because they are themselves computer programs, they appeal to most performance evaluators because of their

understandability and ease of use.

In contrast to monitoring the optimization logic, the development of an experimental simulation model to analyze the techniques could also provide useful results. The Roth logic could be modeled in a top-down, modular fashion using the SLAMII simulation language. The entire execution module could first be represented as a simple SLAM network at Level 1, with subsequent levels of networking developed which could simulate the most detailed PASCAL procedures. Performance criteria could then be evaluated simply by making parametric changes to the networks to simulate command file size, relation size, and other system features which may influence the behavior of the logic. Advantages to modeling the system are:

1. Non-operational code can be modeled. Because the system is being simulated, questions of performance can be answered even before the manipulation language has been completed, a strong consideration when viewing the Roth database.

2. Flexibility. Command files and relations do not have to be recreated in order to perform experimentation; rather, system behavior may be observed under varying conditions simply by making straightforward parametric changes to the SLAMII network.

SUMMARY

The goal of this thesis is to provide two effective means of evaluating the performance of the Roth database data manipulation language; or, more specifically, the efficiency of execution time required to process a relational algebra query and return the results to the user. In order to achieve this goal, four specific areas of performance measurement are recommended.

Three types of measurement, each directed at evaluating the effectiveness of the Roth query optimization logic, are presented in a top-down, hierarchical fashion, beginning with measuring the overall system and ending with measuring the validity of the set of pre-defined rules used to coordinate sort orders and implement the actual operations. Conversely, the fourth type of measurement addressed deals with the optimality of employing a B*-tree technique to index the stored relations used by the system.

Two means of measuring the effectiveness of the database language, monitoring and modeling, provide the method of evaluation. Monitoring has the advantage of being easy to interpret and accurate, but modeling is more flexible and may be used to evaluate non-operational code.

IV PERFORMANCE MONITOR

SYSTEM OVERVIEW

The original implementation of the Roth database was begun on an Intel 8080 system. Due to limited resources, however, further work on the 8080 became impractical. As a result, development was continued on the LSI-11/2 microcomputer system manufactured by the Digital Electronics Corporation (DEC). This 64K-byte sys em features a 16-bit architecture and has eight general purpose registers, with registers 6 and 7 reserved as the system Stack Pointer and Program Counter respectively. There are currently five LSI-11/2 microcomputers, labeled Systems A through E, resident in the AFIT Digital Engineering Laboratory.

The LSI-11/2 supports the UCSD PASCAL operating system and applications programming language, which Roth used to implement his relational database definition and manipulation logic. Furthermore, in order to preclude potential resource limitation difficulties on the LSI-11/2, certain special features of UCSD PASCAL were employed. One such feature, the segmentation feature, permits the compilation of large UCSD PASCAL source files by breaking these files into smaller sectors. The code and data associated with each of these sectors, called Segment

Procedures, reside in memory only while there is an active invocation of that procedure; i.e., the segments are physically swapped in and out of an overlay area in memory, in turn increasing available memory space. Segmentation is accomplished by separately compiling Units and Segment Procedures, linking each procedure to the unit it uses, and then linking all Segment Procedures into one executable program by using the Librarian utility. The Roth database code uses a unit called COMMON, which contains all global variables and structure definitions. A complete explanation of the UCSD PASCAL capabilities appears in the Mau thesis (Ref. 8, pp. 9-26).

In order to set up a software monitor to measure execution times of the optimization modules, three modifications must be made to the existing Roth system. First, a procedure must be written to permit the reading of the KWV11-A real-time clock, in turn indicating the amount of time required to process a given area of logic. The KWV11-A is a programmable clock/counter that provides various means for determining time intervals or counting events. The clock counter is a 16-bit register which can be operated in any of four programmable modes. Because the printed circuit board housing the KWV11-A is a quad board, however, the clock can only be used on System A in the Digital Engineering Lab.

The second modification required to permit system monitoring is the insertion of software "hooks" within the

existing PASCAL code to initiate the reading of the KWV-11A clock. Third, logic must be provided to allow proper communication and interface between the clock reading procedure and the PASCAL host. This objective is accomplished by first storing the clock/counter time in a global PASCAL variable and subsequently placing this value along with an integer value identifying the source of the call into an array to be used during data analysis. These three tasks are developed in detail in the remainder of this chapter.

EXTERNAL SUBROUTINE

The first consideration in implementing the software monitor is designing and coding a subroutine external to the main PASCAL logic which may be called upon to read the real-time clock and store its contents at a location accessible to the host program. Because UCSD PASCAL does not have the capability of reading this low-level real-time clock, the subroutine must be written at the assembly language level.

As previously mentioned, the real-time clock provided with the LSI-11/2 system is the KWV11-A. The KWV11-A has the following features which affect the implementation of the software monitor:

1. 16 bit resolution
2. driven by an external input

3. four programmable modes

The clock can generate interrupts to the processor at given intervals and can run at one of the following five programmable frequencies: 100Hz, 1kHz, 10kHz, 100kHz, or 1MHz. The clock also includes a Schmitt trigger which permits clock initiation as well as program interrupt initiation in response to external events.

The KWV11-A uses two LSI-11/2 system registers, the Control/Status Register (CSR) and the Buffer/Preset Register (BPR). The CSR allows the processor to control the operation of the clock as well as monitor its activities. By using the CSR, the user can enable interrupts, select a mode of operation, start the counter, and monitor trigger events. The BPR, on the other hand, is a 16-bit register that can be loaded from the counter, thus providing the user the ability to measure processing time from event to event.

The external assembly language subroutine uses the LSI-11 instruction repertoire, and is shown in Figure 6. Because the routine is written in assembly language, it must be constructed as an external procedure, beginning with a .PROC statement and ending with a .END. The objective of the subroutine is to read the value of the clock/counter and place it in the PASCAL global variable THYME each time the subroutine is called; additionally, if the time interval between two monitoring events is large

```
          .PROC    CLOCKREAD          ;
          .PUBLIC  THYME              ; GLOBAL PASCAL VARIABLE
          .PUBLIC  COUNT              ; GLOBAL PASCAL VARIABLE
FREQ1     .EQU     61146              ; CSR - FREQ = 1 KHZ
FREQ2     .EQU     61136              ;       FREQ = 10 KHZ
FREQ3     .EQU     61156              ;       FREQ = 100 HZ
KWBPR     .EQU     170462             ; BPR REG AT 170462
KWCSR     .EQU     170460             ; CSR REG AT 170460
OFLVEC    .EQU     440                ; OFLO VECTOR AT 440
ST2VEC    .EQU     444                ; SCHMITT TRIG VECTOR AT 444
          MOV      #ST2SRV,@#ST2VEC   ; ST2SRV INTERRUPT ADDRESS
          MOV      #OFLSRV,@#OFLVEC   ; OFLO INTERRUPT ADDRESS
CLKGO:    MOV      #61146,@#KWCSR     ; LOAD CSR REGISTER WITH -
                                      ;   INTERRUPT ST2 (14)
                                      ;   ST2 INITIATES GO (13)
                                      ;   SIMULATE ST2 (9)
                                      ;   INTERRUPT OFLO (6)
                                      ; CLOCK RATE OF 10KHz
                                      ; MODE 3 (2&1)
          RTS      PC                 ; RETURN TO PASCAL HOST
ST2SRV:   BIT      #100000,@#KWBPR    ; TEST MOST SIG BIT OF BPR
          BEQ      BPRMOV             ; IF MSB NOT SET, BRANCH
          INC      @#COUNT            ; INCREMENT OVFLO COUNTER
BPRMOV:   MOV      @#KWBPR,@#THYME    ; INTERRUPT ADDRESS -
                                      ;    MOVE CONTENTS OF BPR TO THYME
          BIC      #100000,@#THYME    ; RESET MSB (SUBTRACT HALF)
          RTI                         ; RETURN FROM INTERRUPT
OFLSRV:   INC      @#COUNT            ; INCREMENT OFLO COUNTER
          INC      @#COUNT            ; TWICE
          BIC      #200,@#KWCSR       ; CLEAR BIT 7 OF CSR
          RTI                         ; RETURN FROM INTERRUPT
          .END                        ;
```

Figure 6. External Subroutine

enough to cause the clock to overflow, an overflow counter is maintained and stored in global variable COUNT to be used during data reduction.

The logic flow of the external subroutine consists of an initialization portion and two interrupt service

routines. The memory locations of the CSR and BPR are identified through the use of equate statements. The locations of the Schmitt Trigger and Overflow vectors are also defined. The address of the interrupt service routine (located at ST2SRV) is placed into the ST2 vector location and the address of the counter overflow service routine (located at OFLSRV) into the OVFLO vector location. The CSR is then initialized with the value 61146, which sets the appropriate CSR bits to institute the following action:

1. Every time the Schmitt Trigger is fired (i.e., each time the subroutine is entered), an interrupt is generated, passing control to the ST2 interrupt service routine. (Bit 14)

2. Every time the Schmitt Trigger is fired, a bit called the GO bit is set which initiates the clock. (Bit 13)

3. Maint ST2 is set which simulates the firing of the Schmitt Trigger. (Bit 9)

4. Every time the clock overflows, an interrupt is generated , passing control to the overflow interrupt service routine which subsequently increments the overflow counter. (Bit 6)

5. The clock frequency is set to 1 KHz to perform the monitoring function (Bits 5,4, and 3). To increase the frequency of the monitoring clock/counter to 10 KHz, the CSR may be loaded with the value equated to FREQ2. If a

slower frequency is desired, FREQ3 may be employed. A frequency greater than 10 KHz causes problems, however, because overflow conditions may occur during the processing of the external subroutine itself. Considering the fact that the monitor could eventually be employed to time executions requiring more than an hour of execution time, a 1 KHz frequency seems most appropriate.

6. The clock is set to Mode 3, which causes the clock to be reinitialized to 0 every time the Schmitt Trigger fires (i.e., every time the monitor is called). (Bits 1 and 2)

Control is then returned to the PASCAL host.

The KWV11-A internal clock/counter is capable of storing an octal value of 65535. A problem arises, however, when a value of this magnitude is moved into a UCSD PASCAL integer type variable. Any positive number exceeding an octal value of 32767 is considered a negative number when stored as a PASCAL integer. To preclude potential confusion, the overflow counter (COUNT) is incremented each time the clock exceeds 32767. When the ST2 interrupt service routine is called at ST2SRV, the BPR has just been loaded with the contents of the clock/counter. The clock value must subsequently be transferred to the PASCAL variable THYME. First, however, it must be determined if the BPR contents exceed 32767 (octal). If this is the case,

the most significant bit (MSB) if the BPR will be set, and the overflow counter is incremented by one. In either case, the BPR contents are moved into the variable THYME, and the MSB is cleared. Note that the MSB of the BPR was not cleared before the transfer was made, because during this processing the GO bit is set, and the BPR is not capable of being modified while the GO bit is in this status. In effect, the preceeding logic divides the contents of the BPR by 32767 (octal), increments the overflow counter by the value of the quotient, and restores the variable THYME with the remainder. Control is then returned from the service routine.

When the overflow service routine is called, the overflow counter is incremented twice, indicating that 32767 (octal) has been exceeded two times. Bit 7 of the CSR, the overflow flag, is reset to permit subsequent overflow interrupts to occur.

The algorithm used to perform the monitoring function requires the PASCAL host to call an externally assembled procedure which in turn causes the generation of an interrupt. Upon the occurrence of this Schmitt Trigger 2 interrupt, the Buffer/Preset Register is loaded with the contents of the clock/counter, and may be subsequently read by the program. This procedure may seem awkward; it would be more straightforward to simply read the clock during processing. Unfortunately, however, the KWV11-A clock/counter is strictly an internal register, capable of

being read only indirectly via the BPR.

To further illustrate the logic flow of the procedure, let us assume that two calls to the monitor have been inserted into the PASCAL host program. Let us further assume that the time interval between the two calls causes an overflow of the KWV11- A clock. The processing would occur as follows:

1. The monitor subroutine would be entered initially. The ST2 vector would be initialized with the address of the ST2 service routine and the OVFLO vector with the overflow service routine address.

2. The CSR would be loaded and control returned to the PASCAL host program.

3. The Schmitt trigger would be fired. The clock value (0) would be placed in the BPR. Control would pass to the ST2 service routine, where the BPR value would be loaded into the variable THYME. The MSB of variable THYME would be reset, and control would pass back to the PASCAL host program.

4. During the processing of the PASCAL host, the clock counter would overflow. An interrupt would be generated which would cause the execution of the overflow service routine. The overflow counter would be incremented twice. The overflow bit of the CSR which had been set at the time of the overflow would be reset to 0. Control would return to the PASCAL host.

5. When the monitor is called the second time from the PASCAL host, the CSR is again loaded. The ST2 service routine is called and moves the adjusted contents of the BPR, which now contains the elapsed time since the clock overflow, into THYME. If the MSB of the BPR is set, the overflow counter is incremented and the MSB of the updated variable THYME is reset.

Two things are now evident. First, the clock was forced to exceed 32767 (octal) by the number of times indicated in the PASCAL variable COUNT. Second, a value of elapsed time since the last overflow occurred resides in THYME.

CALLING THE MONITOR

Calling the software monitor from the Roth database system is a straightforward task. Because the assembly procedure is set up as a UCSD PASCAL external procedure, it may be called from its host routine just as any PASCAL procedure would be; i.e., by exercising a call to procedure MONITOR. The one consideration when calling the monitor is the identification of the location from which the monitor is being initiated. This identification is made by passing an integer parameter from the PASCAL host to the interface logic which subsequently allows the user to know from where each call was made. Figure 7 illustrates the insertion of three monitor calls into the EXECUTE segment of the host

code.

```
.
.
.
.
IF COMFILE = NIL THEN
  BEGIN
    WRITELN(' NO FILE TO EXECUTE....');
    EXIT(EXECUTE)
  END;
MONITOR(1);
TREE(RELLIST,COMFILE,ERROR,CHAIN);
MONITOR(2);
.
.
.
.
BEGIN
  INSUPS; PRINTTREE;
  MONITOR(3);
  .
  .
  .
```

Figure 7. Calling the Monitor

Because of the ease of calling the monitor, system requirements may be satisfied by inserting calls into appropriate locations within the PASCAL host. Every time new monitor calls are inserted, the appropriate segment must be recompiled and reinserted into the existing

operational code file using the LIBRARY utility.

HOST-SUBROUTINE INTERFACE

Having created the subroutine CLOCKREAD which is responsible for manipulating the KWV-11A clock, as well as having inserted "hooks" into the PASCAL host to initiate the monitoring procedure, the only task remaining before the monitor may be implemented is to establish the interface between the two. Permitting communications between external subroutine and PASCAL host is accomplished largely through the use of the COMMON unit.

The COMMON unit, like all UCSD PASCAL Units, consists of two sections, the interface section and the implementation section. The COMMON unit is written exclusively in PASCAL, but by using the UCSD PASCAL EXTERNAL declaration feature, a small PASCAL procedure resident in COMMON may be called from the host, in turn calling the assembly CLOCKREAD subroutine, thus serving as a "stepping stone" from host to subroutine. This technique is required, because when using segmented PASCAL code, it is imperative that any call to an external procedure or function be made from the same segment which defines that procedure or function.

Figure 8 illustrates the modifications made to the COMMON unit to establish the subroutine-host interface. The host calls the monitor simply by making a PASCAL procedure call using a unique integer parameter to identify the call

```
UNIT COMMON;
INTERFACE
CONST MONTRSIZE = 20;
.
.
.
MONTRCRD = RECORD
    CLCKTIME : INTEGER;
    OVFLCOUNT : INTEGER;
    FNCTION : INTEGER;
          END;
ARRA = ARRAY[1..MONTRSIZE] OF MONTRCRD;
.
.
VAR
.
THYME:INTEGER;
COUNT:INTEGER;
MONTROUTPUT:ARRA;
MONTRPTR:INTEGER;
.
PROCEDURE MONITOR(FUNCT : INTEGER);
.
.
IMPLEMENTATION
.
.
.
PROCEDURE CLOCKREAD; EXTERNAL;
(*
*)
PROCEDURE MONITOR;
BEGIN
CLOCKREAD;
MONTROUTPUT[MONTRPTR].CLCKTIME := THYME;
MONTROUTPUT[MONTRPTR].OVFLCOUNT := COUNT;
MONTROUTPUT[MONTRPTR].FNCTION := FUNCT;
MONTRPTR := MONTRPTR + 1
COUNT := 0;
END;       (*MONITOR*)
.
.
```

Figure 8. Unit COMMON

(e.g., MONITOR(3)). Because MONITOR is identified in the INTERFACE section of COMMON, a call to this PASCAL procedure may be made from any segment of the Roth code which uses UNIT COMMON. In addition to being identified in the INTERFACE section, the PASCAL pocedure MONITOR is coded in the IMPLEMENTATION section of COMMON. Also appearing in the IMPLEMENTATION section is a PASCAL statement declaring CLOCKREAD as an external assembly language procedure.

The logic flow of procedure MONITOR is straightforward. The procedure first calls CLOCKREAD, the external subroutine, which transfers the clock time from the BPR to THYME and moves the number of clock overflows to COUNT. Additionally, the integer parameter passed when MONITOR was called resides in FUNCT. These three values are placed in the record element of an array called ARRA, and the array pointer is incremented by one to point to the next record for subsequent processing. Control is then returned to the calling program. The final result of a series of monitor calls is an array of records, each containing a clock value, a number of overflows, and an identifier indicating from where the monitor was called. The array is then written to diskette by the COMMON resident PASCAL procedure PRINTMON to permit offline data analysis.

In addition to modifying COMMON to allow proper host-subroutine interface, the mechanics used to rebuild the Roth system are also unique. Appendix C outlines the

procedures required to build the system to permit execution of the monitor.

PROCESSING THE MONITOR RESULTS

Once all monitoring has been completed, and the array of clock values has been constructed, the array must be written to diskette to be used by an offline data reduction program which will analyze the results of the monitoring effort. This task is accomplished by the procedure PRINTMON, which, like MONITOR, resides in the implementation area of COMMON. PRINTMON is listed in Figure 9, requires no parameter passing, and may be invoked from any segment which uses UNIT COMMON.

It is worthy to note that either one of two techniques could have been employed to write the monitor results to diskette. Either a PASCAL array could have been created during processing, with the entire array written to diskette, or the result of each monitor invocation could have been written on an individual basis as the results became available. The major disadvantage of writing the entire array is that the array requires notable memory resources in an already restricted environment; conversely, the disadvantage of writing the individual results is that this action would add significant overhead to execution times. The first option was chosen to be implemented, largely because the size of the monitor data array is "adjustable"; by modifying the

```
UNIT COMMON;
INTERFACE
.
.
.
.
PROCEDURE PRINTMON;
.
.
IMPLEMENTATION
.
.
PROCEDURE PRINTMON;
VAR CNT : INTEGER;
    M : INTERACTIVE;
BEGIN
  REWRITE(M,'#5:MONFIL.TEXT');
  WRITELN(M,'     MONITOR RESULTS     ');
  WRITELN(M);
  WRITELN(M,' FUNCTION          TIME          COUNT');
  WRITELN(M);
  FOR CNT := 1 TO (MONTRPTR - 1) DO
  WRITELN(M,'    ',MONTROUTPUT[CNT].FNCTION,'       ',
                   MONTROUTPUT[CNT].CLCKTIME,'      ',
                   MONTROUTPUT[CNT].OVFLCOUNT);
  CLOSE(M,LOCK)
END;   (* PRINTMON *)
.
.
.
.
.
```

Figure 9. Procedure PRINTMON

value assigned to the constant MONTRSIZE in the COMMON UNIT, the corresponding array becomes just large enough to accommodate the number of monitor calls made. The PRINTMON procedure makes use of three UCSD PASCAL features

which enhance the capability of writing the file to diskette. First, the variable M is declared an interactive type variable. Next, the REWRITE statement is used to open and create a new file on Logical Unit 5, to be listed in the disk directory as MONFIL.TEXT. The normal PASCAL WRITELN statements are then used to write the required information, with the variable M used to indicate that the data is to be written to diskette. Finally, the file is closed using the LOCK option, which permanently places the file name in the disk directory. Upon completion of the database processing, the file MONFIL.TEXT may be used to analyze the monitoring effort. Figure 10 displays a call to PRINTMON after TREE and subsequent procedures have been monitored and Figure 11 shows the listing of the resulting file MONFIL.TEXT.

MONITOR OVERHEAD

An issue which must be dealt with is the problem of monitor overhead, i.e., the time required to execute the monitor. Since an attempt is being made to time the execution of a set of logic, it does indeed seem vital that the amount of processor time "wasted" during the actual measurement be accounted for. Monitor overhead may be measured in one of two ways: either analytically or empirically. An analytic measurement would require determining the execution times of each instruction and summing them together to reveal the total overhead

```
BEGIN (* EXECUTE *)
.
.
.
MONITOR(1);
TREE(RELLIST,COMFILE,ERROR,CHAIN);
MONITOR(2);
.
.
  BEGIN
    INSUPS; PRINTTREE;
    MONITOR93);
    PRINTMON;
    .
    .
    .
```

Figure 10. Calling PRINTMON

MONITOR RESULTS

FUNCTION	TIME	COUNT
1	0	0
2	1537	0
3	1408	0

Figure 11. Monitor Results

processing time. An empirical measurement could be performed by executing a series of monitor calls which actually monitor themselves, thereby revealing a good indication of the processing time of each call. A third alternative would be to combine analytic and empirical measurement, in turn determining the execution times of each portion of the monitor logic.

The execution of the monitor is graphically displayed in Figure 12. The PASCAL host places a call to the assembly procedure, passing control to the monitor. After performing some initialization, the procedure loads the CSR which causes the firing of the Schmitt Trigger and initiation of the clock. Control then returns to the host until the Schmitt Trigger interrupt returns control to the interrupt address. The interrupt routine executes, returning control to the host until either a clock/counter overflow occurs, causing the overflow routine to process, or until another monitor call is made.

Executing ten successive monitor calls reveals that the average time required to execute a single call without overflow is 4200 microseconds (4.2 milliseconds), as depicted in Figure 12. Furthermore, analytic measurement using Appendix C of the Digital Microcomputers and Memories Manual (Ref. 9), shows that the actual time required to execute the monitor instructions without overflow

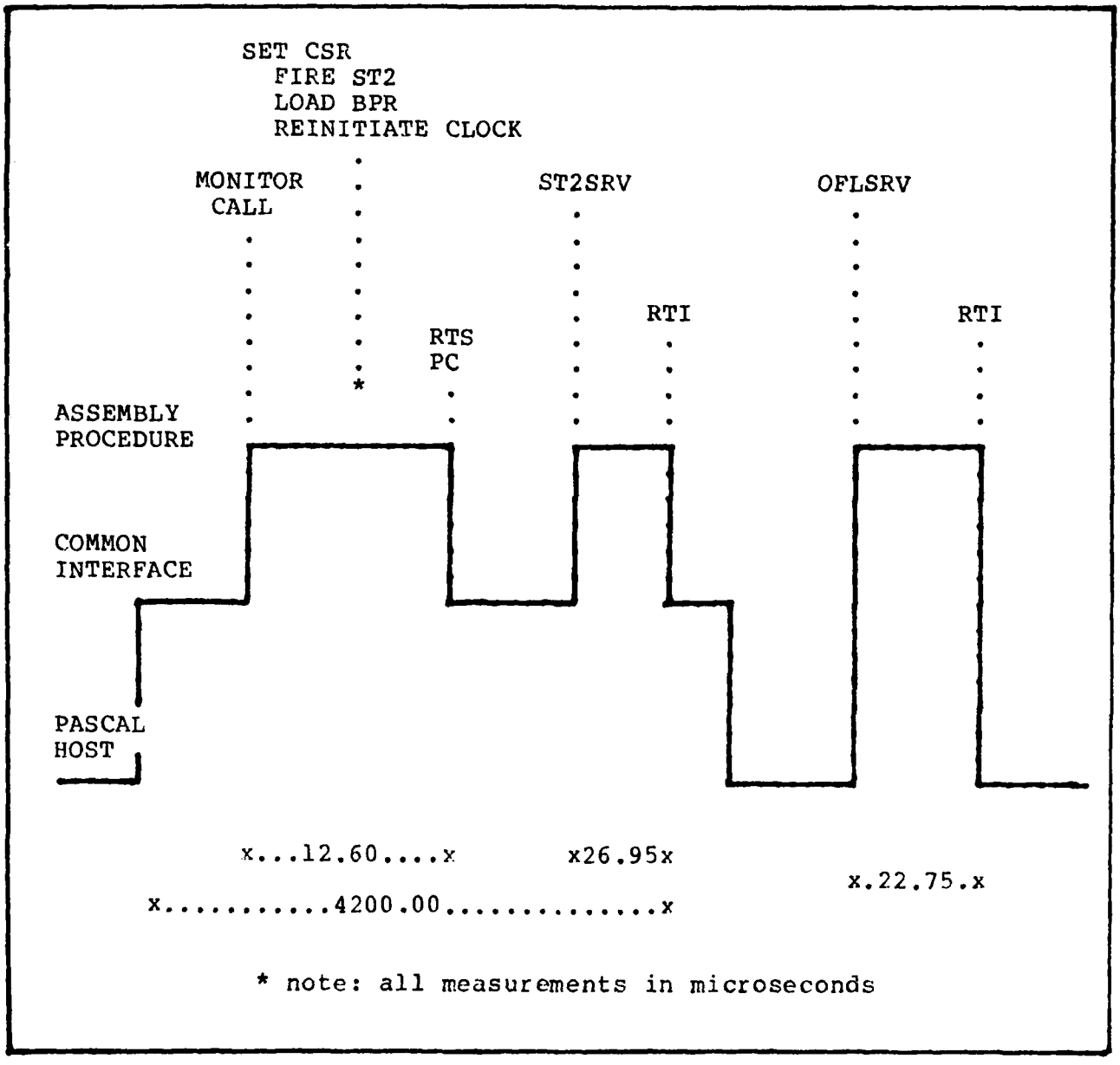

Figure 12. Monitor Overhead

(initialization plus ST2 service routine) is 39.55 microseconds. The processing time required by the overflow service routine is 22.75 microseconds. As one would expect, these figures indicate that the large majority of monitor overhead time (4160.45 microseconds) is consumed by the UCSD PASCAL monitor interface resident in the COMMON module. Mathematically, the monitor overhead time may be represented as follows:

ASSEMBLY SUBROUTINE INITIALIZATION TIME +
ASSEMBLY SUBROUTINE ST2 INTERRUPT SERVICE ROUTINE TIME +
COMMON RESIDENT INTERFACE LOGIC EXECUTION TIME +
(# OVERFLOWS * ASSEMBLY SUBROUTINE OVFL SERVICE ROUTINE TIME) =
TOTAL MONITOR OVERHEAD TIME (1)

or,

4200 microseconds +
(# OVERFLOWS * 22.75 microseconds) =
TOTAL MONITOR OVERHEAD TIME (2)

DATA REDUCTION AND VERIFICATION

The two remaining objectives required to complete the development of the Roth Database monitor are the creation of an offline data reduction program and a test of an instrumented system which will verify that the monitor will

collect data and handle overflow conditions properly.

Appendix D is a listing of program ANALYZE, a PASCAL routine which takes the data recorded in file MONFIL.TEXT and reduces it to yield overall system execution times. ANALYZE basically consists of two parts, the reading of MONFIL.TEXT and the creation of a second disk file, ANALFIL.TEXT which contains the reduced information. After it resets the input file, ANALYZE spaces past the first four header lines and reads the tabular data (Ref. Figure 11) into an array called ANALARRA. An '*' is written to the console screen for every line read from MONFIL.TEXT.

After the array ANALARRA has been created, the data it contains is transformed into the final monitoring results and written to diskette file ANALFIL.TEXT, with an "*" printed to the screen corresponding to every line written to disk. The first step of this process is to determine the number of times the actual KWV11-A clock/counter overflowed (OVFLTOT), in addition to the value recorded in the array (ANALARRA[INCR].OVFLCOUNT). The total overhead is then calculated using Equation 1, where OVHEAD is equated to the sum of the initialization time, ST2 service time, and PASCAL overhead time. The total processing time is then calculated using the following formula:

```
(OVERFLOW COUNT * 32767) +
CLOCKTIME -
```

TOTAL OVERHEAD =

TOTAL PROCESSING TIME (3)

Two techniques were employed during this calculation to permit accurate results. First, variable FINALVAL was declared as a UCSD "long" integer, capable of storing a signed decimal value twenty digits in length (Ref. 19, p. 155). Had this procedure not been used, a maximum value of only 32767 could have been stored in FINALVAL. Second, the value of TOTOVHED had to be rounded off to ensure compatability within the mathematical expression.

Before any meaningful results can be drawn from monitoring the Roth Database optimization logic, a test of the monitor needs to be performed to verify the following capabilities:

1. Absence of obvious run-time errors.
2. Proper advancement of the clock/counter.
3. Resetting of the BPR to zero each time the trigger is fired.
4. Proper advancement of the overflow counter.
5. Accurate data reduction and presentation.

These capabilities were indeed verified using the following techniques:

1. Run-time errors were corrected during normal

system execution.

2. Analysis of the results written to disk file MONFIL.TEXT show that the BPR values placed into the file contained different values for different procedures monitored. Additionally, these values appeared to be commensurate with the time these procedures should require to process relative to one another. These two observations supported the supposition that the clock/counter was being properly advanced.

3. Resetting the BPR at the firing of the trigger was verified by the fact that the CLCKTIME results stored in MONFIL.TEXT are obviously not cumulative.

4. In order to verify the advancement of the overflow counter, two dummy PASCAL FOR .. DO loops were inserted into the Roth DML code and monitored successively. The first test, which consisted of an outer FOR .. DO loop of twenty iterations and an inner FOR .. DO loop of 3200 iterations, caused a value of 9 to be placed in the overflow counter, and a value of 17562 placed in the CLCKTIME variable. Reduction of these values yielded a processing time of 312474 milliseconds. The outer loop then was modified from twenty iterations to forty iterations. It would intuitively seem that the total operating time of the test logic should also approximately double. In fact, the overflow counter went from a value of 9 to 19 and CLCKTIME changed to 3057, yielding a total value of 625649, almost exactly double the first calculated result. Additional

modifications further confirmed that the overflow counter was incremented properly, all the way up to a value of 57.

5. By processing the values appearing in MONFIL.TEXT using a calculator, the offline reduction program ANALYZE was verified as correct.

V MODELING THE ROTH OPTIMIZATION LOGIC

BACKGROUND

Monitoring the performance of the Roth database optimization logic is a straightforward means of measuring the effectiveness of these modules. Unfortunately, however, successful monitoring is based on the premise that the code being measured is operational; it is not feasible that monitor hooks be placed in software that does not achieve its intended objectives. This limitation to monitoring makes evident one of the advantages to modeling the performance of a system - design, not code is the actual object of the model.

A system may be thought of as a collection of interacting elements affected by outside forces; conversely, a model is an abstraction of this system. In order to effectively create this abstraction, two things must be established immediately: the purpose for modeling the system and the elements of the system which must be included in the model to provide an accurate representation. The modeling process may be depicted as:

1. Define the purpose of the model.
2. Establish the boundaries of the system to be modeled.
3. Determine the level (or levels) of detail to be

represented.

4. Establish system performance measures.

5. Define design alternatives (parametric and structural) which, if implemented, could lead to improved performance.

6. Assess results, experiment with alternatives, and implement the most effective model.

A pictorial representation of this process appears in Figure 13.

The purpose of this chapter is to address, in detail, the six steps of the modeling process as it applies to the Roth database optimization design. Since a model may be thought of as a laboratory version of a system, the overriding objective motivating this modeling effort is to measure the effectiveness of the theories included in the optimization design and, if required, suggest improvements to the system which could enhance processing efficiency.

A simulation model which represents a system is classified as one of two types: discrete change or continuous change. In most simulation models, including a model of a database system, time serves as the model's independent variable. The means by which the dependent variables fluctuate as a function of time, i.e., at discrete time intervals or continuously over the time spectrum, determines the classification of the model. It is noteworthy that these classifications identify models, not systems, and

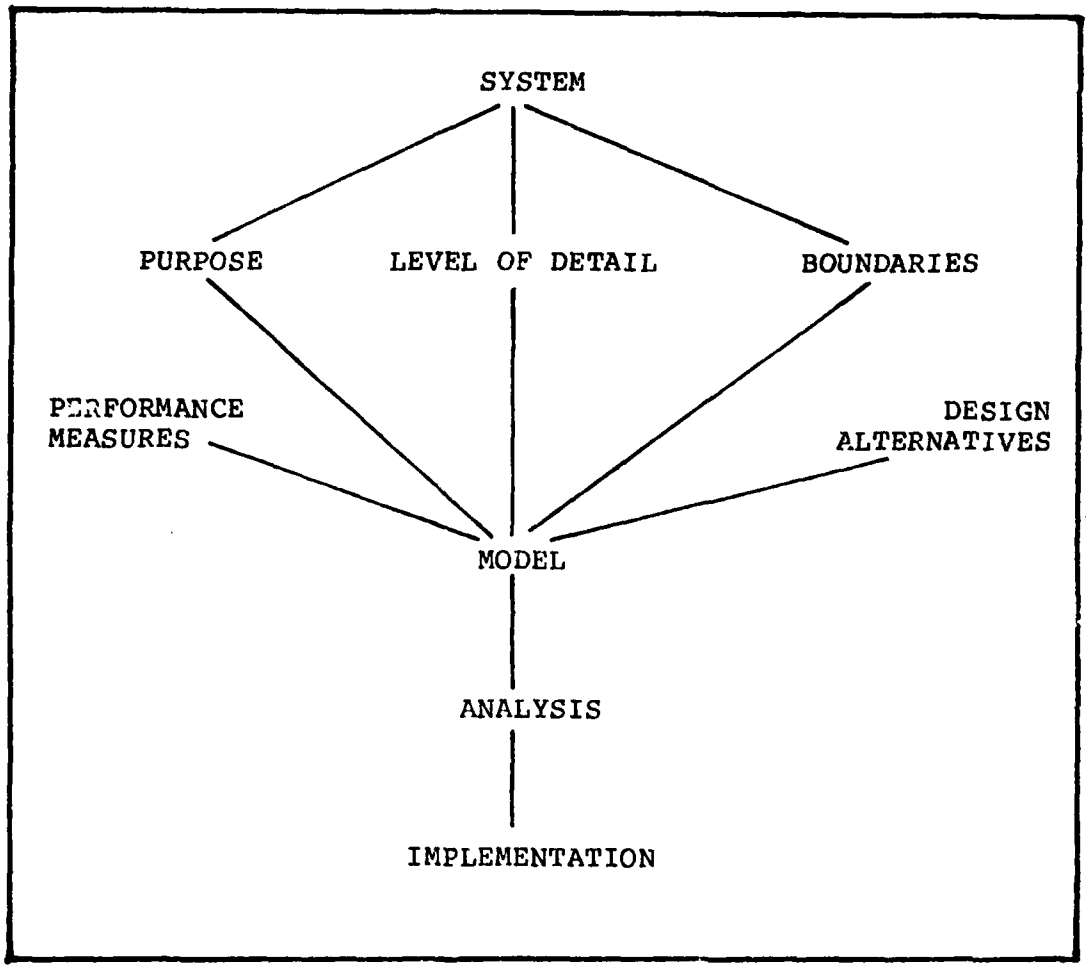

Figure 13. The Modeling Process

that a single system could possibly be represented by either a discrete model or a continuous model (or a combination of the two, called a combined model).

SLAM, the Simulation Language for Alternative Modeling, is a high order modeling language which permits simulation in any of the three modes: discrete, continuous, or combined. SLAM employs a network structure which consists of symbols called nodes and branches. These symbols, which depict such items of interest as queues, servers, and decision points, are combined into a single network which represents the system being modeled. Entities are then created and allowed to flow through this pictorial representation, while statistics are simultaneously being generated which consequently provide insight into the capabilities of the system. In addition to the standard capabilities provided with SLAM, the optional use of FORTRAN user-written subroutines expands the potential for the model to provide a realistic representation of the subject.

Before addressing the model of the Roth logic, a brief description of the key SLAM capabilities is appropriate. The CREATE node is used to generate entites within the system and permits user specification of interarrival time, maximum number of entities created, and number of emanating activities. The QUEUE node permits the delay of entities at a specified location of the network until the appropriate server becomes available. The service

activity represents actual processing in the system and either emanates from a queue or is chosen from other qualified servers by a SELECT node. The GOON node provides a routing capability to another point in the network with every entering entity passing directly through the node. The COLLECT node is used to collect statistics related to either the time an entity arrives at a node or a variable at the entity arrival time.

PURPOSE OF THE ROTH MODEL

The purpose of a model of the Roth database optimization logic is to provide an accurate representation of data flow beginning with the initial execution of a command file through the completion of the execution of the RUN module. SLAM generated statistics provide an excellent indication of the processing time required by each logic module, ranging from entire segment to small procedure. Each entity flowing through the system represents a relational algebra command, a multi- command query, an operator tree, or a network of trees depending on the specific application and location within the system, with attributes assigned to these entities characterizing their complexity, type, and anomalies. By modifying these parameters along with the structure of the network, potential optimization logic bottlenecks and areas requiring improvement can be identified.

SYSTEM BOUNDARIES

In many modeling applications, establishing system boundaries is a difficult task which is even sometimes overlooked. One of the keys to a successful, meaningful model is clearly defining what it is that needs to be modeled. If only a portion of an operational activity is to be analyzed, for example, it is usually not necessary to model the entire organization. It is absolutely crucial that a clear beginning point and terminal point be established before the modeling effort can proceed.

The goals set forth in the requirements chapter of this thesis dictate that the Roth database system model should pertain to the optimization logic contained within the data manipulation language (DML), thus establishing the system boundaries to be modeled. Due to the modular design of the Roth system, the four optimization modules (TREE, SPLITUP, OPTIMIZE and RUN) are all controlled by a central driver, the EXECUTE procedure. It is noteworthy that the top-down, modular construction of the database permits a very straightforward interpretation of optimization logic boundaries.

LEVELS OF MODELING DETAIL

Due to the complexity of the Roth optimization logic, the best technique used to model the system is also a top-down, hierarchical approach, beginning with a simplistic model of the modules as a whole, and ending with detail

which depicts individual PASCAL procedures. The major advantage to this approach is its vivid representation of the system. Appendix A contains SLAMII network diagrams which depict the first two levels of representation of the Roth optimization modules. Each of these diagrams will be described in detail.

LEVEL I

The first SLAM diagram, a LEVEL I representation, serves as a simplistic model of the Roth optimization modules. A simulation of the Roth logic at this overview level of detail functions as an introduction to the processing flow of the modules. At this level of representation, a single entity corresponds to a given relational algebra command file, because an overall view of the optimization logic evaluates the effectiveness of processing entire command files rather than individual relational algebra commands. Figure 14 depicts the data flow represented by the LEVEL I model.

Simplistically stated, a command file is presented as input to the optimization logic. This transaction is represented by the creation of an entity in the LEVEL I model. A total of five entities are created, each corresponding to one of the benchmark queries provided in

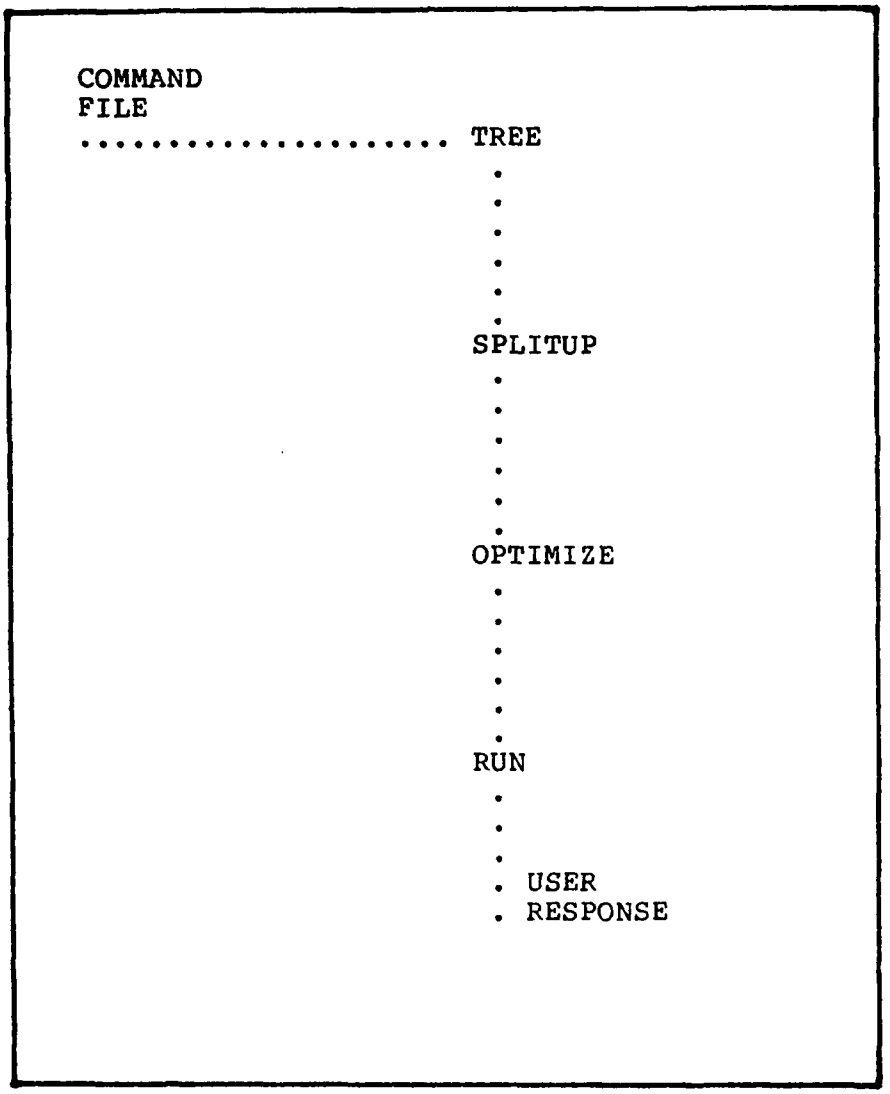

Figure 14. Level I Overview

Appendix B. The Roth system completely processes a given command file before accepting another as input. The LEVEL I model simulates this by forcing an entity to wait at the beginning of the simulation flow until the previous entity is completely through the system. The four optimization modules are then encountered in order and the entity terminates as a response to the user. Upon termination, the succeeding simulated command file is permitted to begin processing through the optimization logic.

LEVEL II

The LEVEL II diagrams appearing in Appendix A provide a more detailed representation of the same logic modeled in the LEVEL I design. In this instance, each optimization module is represented by a single SLAM diagram; however, as an entity exits one module it becomes the input to the next. This process ties the modules together and provides a single, stand-alone representation of the Roth optimization logic at a second level of detail. Unlike the LEVEL I model which simulates the processing of a set of queries, the LEVEL II model simulates the in-line processing of individual command files, each consisting of relational algebra commands.

The first LEVEL II SLAM diagram represents the TREE optimization procedure. A given command file, which

constitutes the input to the TREE module, is simulated by creating the number of entities corresponding to the number of commands in the file. These entities then pass through the TOKEN procedure of the Roth code which returns the type of command being examined. The remainder of the TREE module processes these commands individually; thus, after the execution of the TOKEN procedure, each command is detained until the preceeding command is allowed to complete TREE processing. The remaining TREE processing is merely a call to one of five procedures: DUIP, SELECT, JOIN, PROJECT, or DIVIDE. In the actual system, these procedures are responsible for creating the corresponding node of the operator tree. The specific call depends upon the type of relational algebra command being executed. At the completion of this procedure, the subsequent entity is permitted to proceed. All entities completing the TREE processing are discarded except the last one, which now simulates the network of operator trees used as input to the SPLITUP module.

The next LEVEL II diagram represents the second optimization module, SPLITUP. At this level of detail, SPLITUP is straightforward to model, consisting of five submodules: FINDHEADS, LONGTREE, FIXFIELD, DIVORCE, and REVCHAIN. SPLITUP receives a single entity, the network of shared trees provided by TREE. The entity first passes through activity FINDHEADS, which represents the linking of the network root nodes. Next, procedure LONGTREE sorts this

chain of root nodes, placing the root of the tree with the greatest number of shared subtrees first, and the root of the tree with the least number of shared subtrees last. The next simulated procedure is FIXFIELD, which initializes each node's attribute field. The entity next encounters the DIVORCE activity, which separates the shared subtrees from each tree of the network. Finally, REVCHAIN is encountered. REVCHAIN reverses the order of the root nodes to permit the formerly shared subtrees to be executed before the results of these operator subtrees are utilized. The model of procedure SPLITUP terminates with the creation of multiple entities, each representing an individual tree containing no shared subtrees. These individual trees condstitute the input to the OPTIMIZE module.

The third SLAM diagram represents the OPTIMIZE module of the Roth optimization logic. As was the case with the TREE simulation, entities are only permitted to process individually because the actual OPTIMIZE logic processes a single tree at a time. As in the system itself, this portion of the LEVEL II model depicts OPTIMIZE as a sum of five sub-procedures: COMBOOL, SELDOWN, SIMSEL, PROJDOWN, and ELIMDUPROJ.

COMBOOL, the first procedure simulated, is responsible for transforming a unique tree structure called a "boolean subtree" into a single operator having a single compound predicate. The algorithm employed by COMBOOL is a direct implementation of one of the optimization techniques

under investigation; thus, the experimental modeling of this procedure at more detailed levels will be significant. The SELDOWN procedure, executed next by the OPTIMIZE module, moves SELECT operators down the operator tree. The tree entity next encounters the SIMSEL activity, which simplifies the boolean predicates of the SELECT operators. The next simulated activity encountered is the PROJDOWN procedure, which moves PROJECT operators down the operator tree. Finally, the entity traverses the ELIMDUPROJ procedure, which eliminates duplicate PROJECT operators. After these five activities have been traversed, the succeeding entity is permitted to enter the OPTIMIZE logic. The input to OPTIMIZE was a series of individual trees created by SPLITUP. The result of OPTIMIZE is a series of optimized versions of these trees.

The final LEVEL II SLAM diagram depicts the RUN module of the Roth Database optimization logic. The baseline design of this procedure was presented in the Roth Thesis (Ref. 17, p. 77) and partially coded as an independent study by Lt. Peter Raeth. The module implements the technique presented in the Smith & Chang paper (Ref. 18), called the Coordinating Operator Constructor. The model shows that the single entity, representing the optimized operator tree produced by OPTIMIZE, first flows through activity INSUPS. INSUPS serves as a prelude to the actual algorithm which links the operator nodes. The entity then simulates being processed by the activities UPTREE and

DOWNTREE, two submodules which actually perform the RUN optimization algorithm. Finally, a procedure tentatively called EXEC is simulated. EXEC will be responsible for executing the procedure calls created by DOWNTREE. All entities which complete EXEC processing, except the last one, are discarded. The last entity exits the system representing the result of the query being returned to the user.

Models of the Roth query optimization logic have now been designed at the first two levels of detail. While it is beyond the scope of this thesis effort to represent the system at any further detail level, it is noteworthy that these two baseline models do provide an excellent overview of the Roth database optimization modules and an essential beginning point for future Roth logic modeling.

SYSTEM PERFORMANCE MEASURES

The next step in the modeling process is the establishment of system performance parameters; i.e., what values should be used to accurately portray the Roth system processing times, what modifications should be made to these parameters to correctly reflect different query operating characteristics, and what SLAM statistics should be used to evaluate the outcome of these modifications?

Because the majority of time devoted to this thesis was spent developing the software monitor and the design of

a portion of the optimization logic has not yet been completed, the detailed development of these performance measurements was not determined to be within the scope of this effort.

It is noteworthy, however, that determining activity durations which represent the execution time of sets of optimization logic is the first step required to parametrically depict the Roth system. The development of these values may be performed in one of two ways: empirically or analytically. Empirical parameter formulation implies that duration values would be assigned based on observation. Since the Roth database system is not yet operational for complex queries, empirical assignment of parameter values is currently impractical.

Analytic calculation of activity duration times, then, is the next task required to continue this modeling effort. Analytically determining these execution times will be a non-trivial task requiring the analysis of the number of lines of executed code as well as the number of I/O transactions performed during the processing of a given relational algebra query.

DEFINE ALTERNATIVES, EXPERIMENT, AND IMPLEMENT

The final two steps in the modeling process are to analyze the results of the simulation effort and attempt to detect possible weaknesses in the optimization logic which, if corrected, could further decrease the amount of execution

required to perform a given user query. Having uncovered these potential deficiencies in the system, either parametric or structural changes to the model can be made, and the model can be executed again, revealing if these revisions are beneficial. Based on the observations provided by the modifications to the model, permanent design and implementation changes can be made to the Roth system which will improve the processing efficiency of the data retrieval function.

SUMMARY

Due to the complex nature of the Roth optimization modules and the time constraints imposed on the completion of this project, coding and implementing the model was not accomplished. Instead, the purpose of the Roth logic model was defined and the boundaries of the system to be simulated were established in conjunction with the requirements set forth in Chapter 3 of this thesis. In addition, the first two levels of detail were established and represented in the form of SLAM network diagrams. The next logical step of this task would be to continue model development to the third, fourth, and even fifth levels of detail. In concert with this activity, critical system parameters have to be established. Finally, the diagrams need to be converted to SLAM code, implemented, analyzed, and modified to provide experimental results.

VI CONCLUSION

SUMMARY

There were three objectives pursued as the goal of this thesis. The first objective was to develop an understanding of state of the art methods used to measure the performance of database management systems. This objective was satisfied as a result of the literature searching accomplished during the initial stage of the effort.

The second objective of this endeavor was to develop a practical method of measuring the efficiency of a set of relational algebra query optimization techniques integrated within the data manipulation language of the Roth Pedagogical Relational Database. Research indicated that not one, but two methods could be used to perform this measurement. Monitoring the execution of the optimization logic would clearly display the amount of time required by individual modules to process a set of benchmark queries designed to test the system's capabilities. As an alternative to monitoring, modeling the Roth optimization system would provide the capability of evaluating peformance even before system implementation.

A performance monitor was developed using a combination of UCSD PASCAL and assembly level programming designed to measure the execution time of the Roth

database query optimization modules. Although the monitor was initially designed strictly for this purpose, it is noteworthy that use of this software tool is equally applicable to any UCSD PASCAL program implemented on the LSI-11/2 Microcomputer. The monitor may be initiated at any point in PASCAL logic by merely calling PASCAL procedure MONITOR.

A model of the Roth optimization logic was also initiated as part of this thesis effort. It was determined that effective modeling of the Roth system should be approached in a hierarchical manner, beginning with a LEVEL I overview of the modules to be simulated. Subsequent models of the system could then be developed, each with increased detail which would eventually lead to an experimental indication of the merit of the optimization techniques.

The third objective of the project was the implementation of the optimization logic monitor followed by as much implementation of the model as permitted during the time allotted to complete this effort. This objective was only partially satisfied.

As expected, the greatest liability encountered when attempting to implement a relational database on a microprocesser is resource limitation. At the time the monitor development was nearing completion, and execution of the Roth manipulation logic using the benchmark queries in Appendix B was beginning, memory limitation problems

became apparent. As a result, only minimal relational algebra queries, consisting of two commands, could be used to test the system. While these small queries were sufficient to validate the monitor, they were unfortunately not large enough to provide conclusions pertaining to the effectiveness of the optimization logic. The model of the system, designed through the second level of detail, provides an excellent overview of the optimization logic as well as a beginning point for further development, but will not provide results until the coding and implementation stages of more detailed models have been completed. Two noteworthy areas of difficulty were uncovered during this thesis effort. They are:

1. Available documentation describing the Version II UCSD PASCAL System is weak. This difficulty was especially evidenced during the early implementation of the monitor. According to the Version II manual, implementing the external assembly language procedure should be a straightforward task, simply consisting of declaring the external procedure and calling it as any other PASCAL procedure would be called. What is not documented, however, is that when attempting to use this technique within segmented code, a unique problem arises.

Due to the segmentation of the Roth data manipulation language, applications procedures from which monitor calls are made reside within one of these PASCAL segments. In

order to consolidate all global variables and common utility procedures, Roth dedicated a PASCAL unit as a depository for these common elements. It initially seemed appropriate to declare the external assembly program in the COMMON unit, and simply call it from one of the segments of code. The manual implied that this procedure was legal and would provide predictable results.

The implementation of this technique, however, resulted in an execution error. Much time and effort was devoted to attempting to correct this error, including correspondence with the SOFTECH Corporation, the APPLE Computer company (which has a similar segmented UCSD PASCAL system), and the University of California at San Diego microprocessor laboratory, all to no avail. Finally, at the suggestion of my thesis advisor, Dr. Hartrum, another technique was attempted. Rather than call the procedure from a segment of code, the PASCAL procedure which actually calls the monitor was inserted into the COMMON unit. This procedure is then called from the segment of PASCAL code, effectively ceating a "stepping stone" affect. The implementation of this technique executed properly, indicating that an external assembly procedure can only be called from the segment (or unit) which declares it.

2. A secord technical area of difficulty arose during the actual testing of the monitor. The Microcomputer

Interfaces Handbook published by the Digital Corporation (Ref. 10), provided the documentation describing the KWV11-A clock. While this documentation was generally acceptable, it did not specifically indicate how the Schmitt Trigger was fired; i.e., how to initiate the loading of the BPR with the contents of the counter. With the assistance of Mr. Dan Zambon, AFIT DEL Engineer, and a call to the local DEC repesentative, it was learned that setting bit 9 of the CSR simulates the firing of the Schmitt Trigger. Operationally, then, every time the monitor is called, the CSR is loaded with a value which sets bit 9, in turn firing the trigger and loading the BPR with the clock value.

RECOMMENDATIONS

The recommendations for follow-on effort to this thesis are as follows:

1. Discover a means of overcoming the LSI-11/2 memory limitation problem which disallows the execution of complex queries; once this dilemma has been corrected, monitor the execution of the optimization logic in accordance with the requirements set forth on this thesis to determine the affect these modules have on overall system performance.

2. Complete the design, coding, and implementation of the RUN module to incorporate the Coordinating Operator Constructor techniques presented in the Smith & Chang paper (Ref. 18); monitor these techniques as part of the overall

optimization logic.

3. Investigate the possibility of extending the model of the optimization modules to a model of the entire Roth system, at least at an an overview level of detail to provide a more concrete view of the interaction of the data manipulation language.

4. Further develop the baseline model presented in this thesis by carrying it to the fifth or sixth level of detail; introduce parametric and structural changes to the model based on experimental results, in turn leading to more productive enhancements of the optimization techniques employed.

FINAL COMMENT

Relational databases provide the wave of the future in the sea of management information systems. Additionally, as hardware miniaturization becomes more prevelent in the area of data processing, increasing emphasis is being placed on the improved capabilities of microprocessors. Accordingly, more and more work is going to be performed in an attempt to implement relational databases on microprocessing systems. Two areas of difficulty are going to surface repeatedly during this implementation: optimization of retrieval time and efficient use of storage resources. Hopefully, through efforts such as this one, microprocessor resident relational databases will become practical and serve the needs of a variety of users.

BIBLIOGRAPHY

1. Date, C.J., An Introduction to Database Systems (Second Edition). Reading: Addison-Wesley, 1977.

2. Ferrari, Domenico, Computer Systems Performance Evaluation. Englewood Cliffs: Prentiss-Hall, Inc., 1978.

3. Fonden, Robert W. Design and Implementation of a Backend Multiple- Processor Relational Database Computer System, AFIT Thesis, 1981.

4. Haerder, Theo "A Generalized Access Path Structure," ACM Transactions on Database Systems,3 (3): 285-298 (September 1978).

5. Hall, P A V "Optimisation of a Single Relational Expression in a Relational Data Base System," IBM Journal of Research and Development, 20 (3) : 244-257 (1976)

6. Hawthorn, Paula, & Stonebraker, Michael, "Performance Analysis of a Relational Database Management System," ACM, 1979.

7. Kambayashi, Yahiko, Database, A Bibliography. USA: Computer Science Press, 1982.

8. Mau, James D. Implementation of a Pedagogical Relational Database System on the LSI-11 Microcomputer, AFIT Thesis, 1981.

9. Microcomputers and Memories. Digital Equipment Corporation Handbook. Digital Products Marketing, 1981.

10. Microcomputer Interfaces Handbook. Digital Equipment Corporation Handbook. Digital Products Marketing, 1981.

11. Morris, Michael F. & Roth, Paul F., Computer Performance Evaluation for Effective Analysis. New York: Van Nostrand Reinhold Co., 1982.

12. Oliver, N.N., & Joyce, John, "Performance Monitor for a Relational Information System," Proceedings of the Annual Conference of the ACM, Houston (October, 1976).

13. Pritsker, A. A. B. & Pegden, C. D., Introduction to Simulation and SLAM. West Lafayette: Systems Publishing Corporation, 1979.

14. Rodgers, Linda, The Continued Design and Implementation of a Relational Database System, Masters Thesis, Air Force Institute of Technology, Dayton, Ohio, 1982.

15. Rosenberg, Arnold L., and Snyder, Lawrence, "Time- and Space- Optimality in B-Trees," ACM Transactions on Database Systems, 6 (1): 174-193 (March 1981).

16. Ross, Douglas T., "Structured Analysis(SA): A Language for Communicating Ideas," IEEE Transactions on Software Engineering, SE-3 (1): 16-34 (January 1977).

17. Roth, Mark A., The Design and Implementation of a Pedagogical Relational Database System, Masters Thesis, Air Force Institute of Technology, Dayton, Ohio, 1979.

18. Smith, John Miles, and Chang, Philip Yen-Tang, "Optimizing the Performance of a Relational Algebra Database Interface," Communications of the ACM, 18 (10): 568-579 (October 1975).

19. UCSD (Mini-Micro Computer) PASCAL, Version II.0, Institute for Information Systems, University of California, San Diego (March 1979). (Available through AFIT/ENE).

20. Yao, S. Bing, "Optimization of Query Evaluation Algorithms," ACM Transactions on Database Systems, 4 (2): 133-155 (June, 1979).

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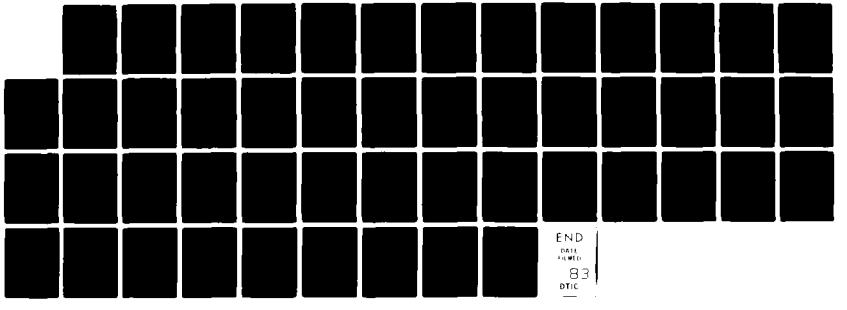
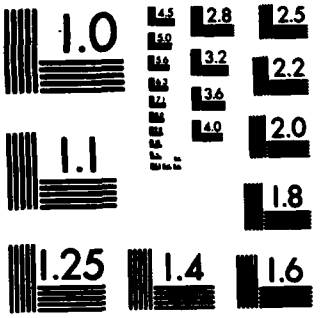




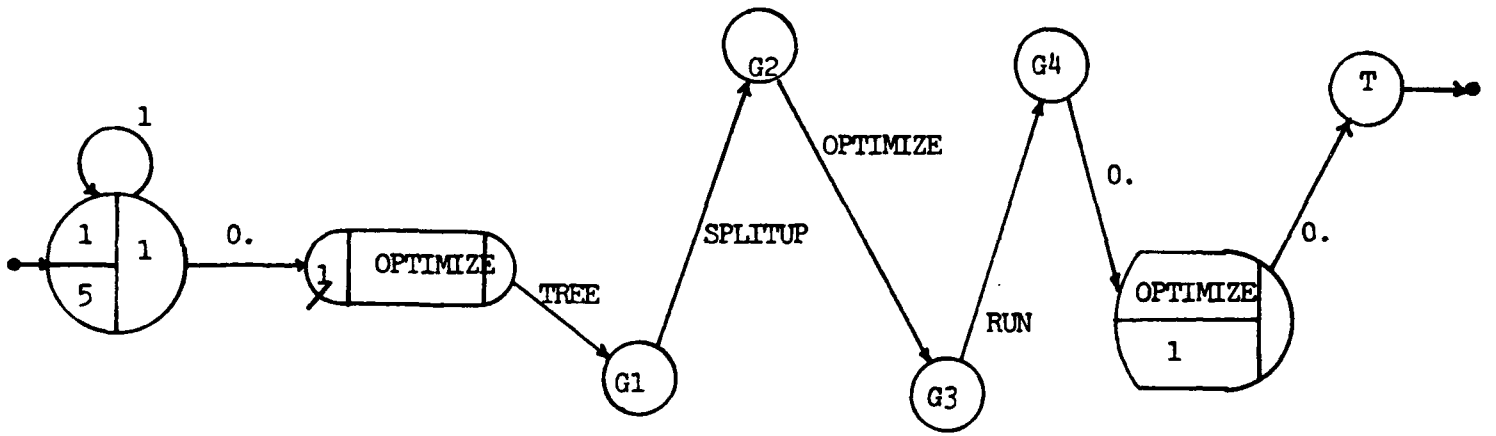
APPENDIX A

ROTH OPTIMIZATION LOGIC MODEL - SLAM NETWORK DIAGRAMS

This appendix is a collection of SLAM network diagrams which depict the Roth database system at the first and second levels of detail.

The first SLAM diagram serves as an overview of the Roth optimization logic and is designed at detail LEVEL I. At this level, an entity in the system represents an entire relational algebra query. For this baseline model, five queries are created by the CREATE node, each corresponding to one of the benchmark queries appearing in Appendix B. The creation of the queries begins at system time zero, and the entities are created at an inter-creation time of 1 time unit. One time unit was nominally chosen as a value for this parameter because the inter-arrival rate is insignificant; after all entities are created, only one is allowed to proceed through the logic at a time. After creation, an entity first encounters an AWAIT node which monitors the status of the SLAM RESOURCE Optimize. The purpose of this technique is to preclude an entity from processing through the optimization logic until the preceeding entity has completed executing. This is done to simulate the fact that the Roth logic processes a single

command file at a time. If the RESOURCE is free, the entity seizes its services and proceeds. The simulated command file encounters four successive activities, corresponding to the four Roth optimization modules: TREE, SPLITUP, OPTIMIZE, and RUN. After completing the RUN activity, the entity frees the Optimize RESOURCE, in turn permitting processing of the subsequent command file. Finally, the entity terminates, simulating a response to the user.



OPTIMIZATION
MODULES

The LEVEL II representation in Appendix A presents the model of the Roth optimization logic at the next level of detail. LEVEL II actually consists of four individual diagrams, each corresponding to one of the optimization modules. Each diagram is related to the other three in that as is the case with the logic represented, the result of one optimization module becomes the input to the next.

The first LEVEL II diagram represents the TREE optimization module. At the CREATE node, a set of n entities, each representing a relational algebra command, is created. Because TREE is the first of the four optimization modules, creating this command file simulates the input of a command file to the TREE procedure in the actual system. The number of commands created depends upon the size of the query being experimented with. Each entity generated is then assigned an integer value which corresponds to one of the eight possible relational algebra command types used by the Roth database system. The integer designations are:

1 - UNION

2 - DIFFERENCE

3 - INTERSECT

4 - PRODUCT

5 - SELECT

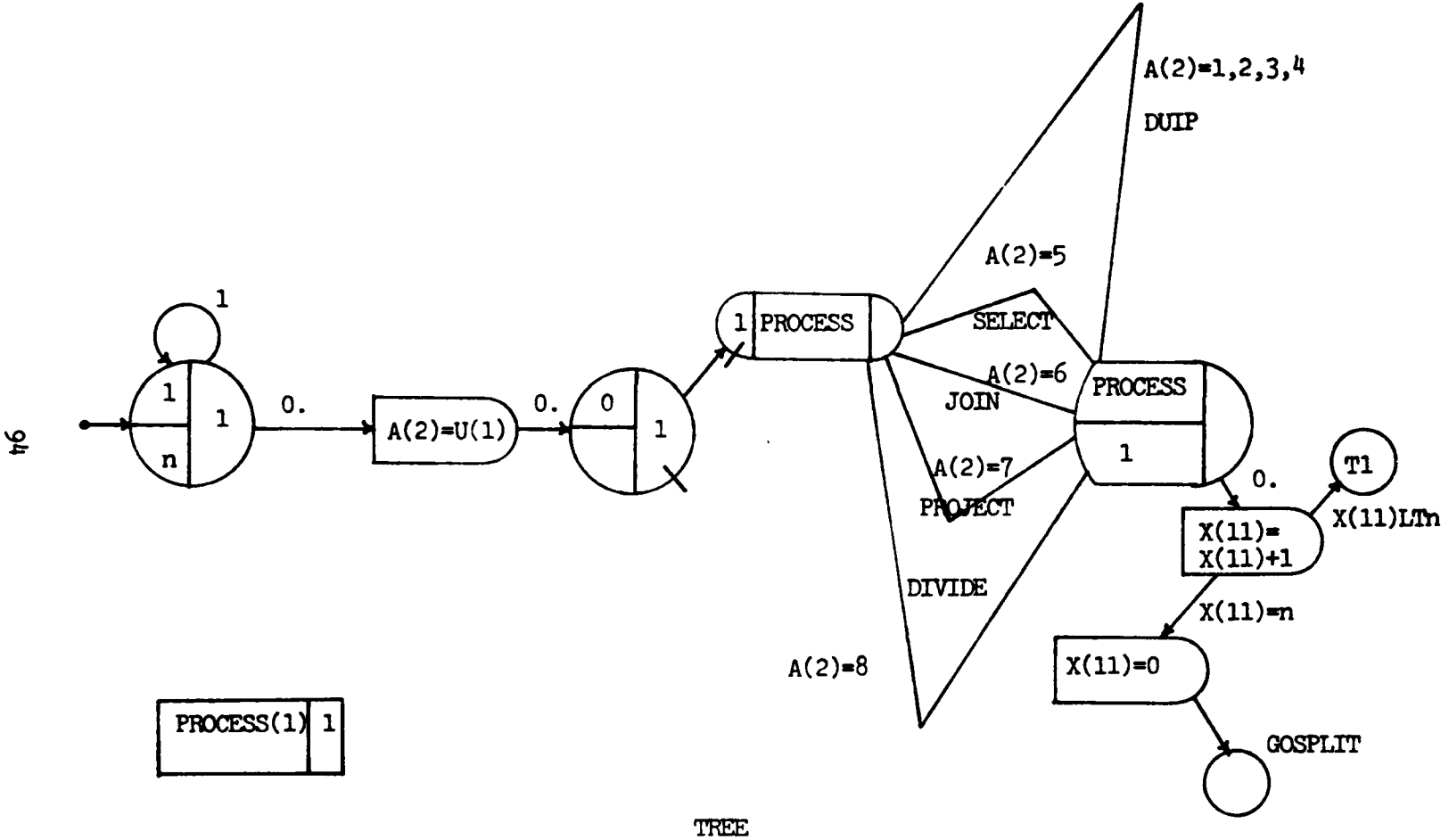
6 - JOIN

7 - PROJECT

8 - DIVIDE

After the entity is assigned its type representation, it passes through a SLAM service activity which simulates the TOKEN procedure. In the actual system, TOKEN returns the type name of the command being processed. At this point, the entities are queued, allowing them to be individually processed by the remainder of the TREE procedure. The actual TREE processing is a call to one of five sub-procedures: DUIP, SELECT, JOIN, PROJECT, or DIVIDE. The specific call being made depends upon the type of command being processed; i.e., the function name returned by TOKEN. This processing capability is treated as a resource in the model, with each entity in the queue individually seizing control of processing and subsequently freeing the resource when it has completed, in turn permitting the next entity to process. The type of processing chosen is based on the integer command type representation acquired at the assign node. After processing is completed, the entity increments a counter kept in variable XX(11) and either exits the model at terminal node T or continues through GOON node GOSPLIT, depending on whether it was the last entity created; i.e., the last command in the query. When the last entity passes through the GOON node, it represents a single network of

operator trees created by procedure TREE which also serves as input to the SPLITUP module.

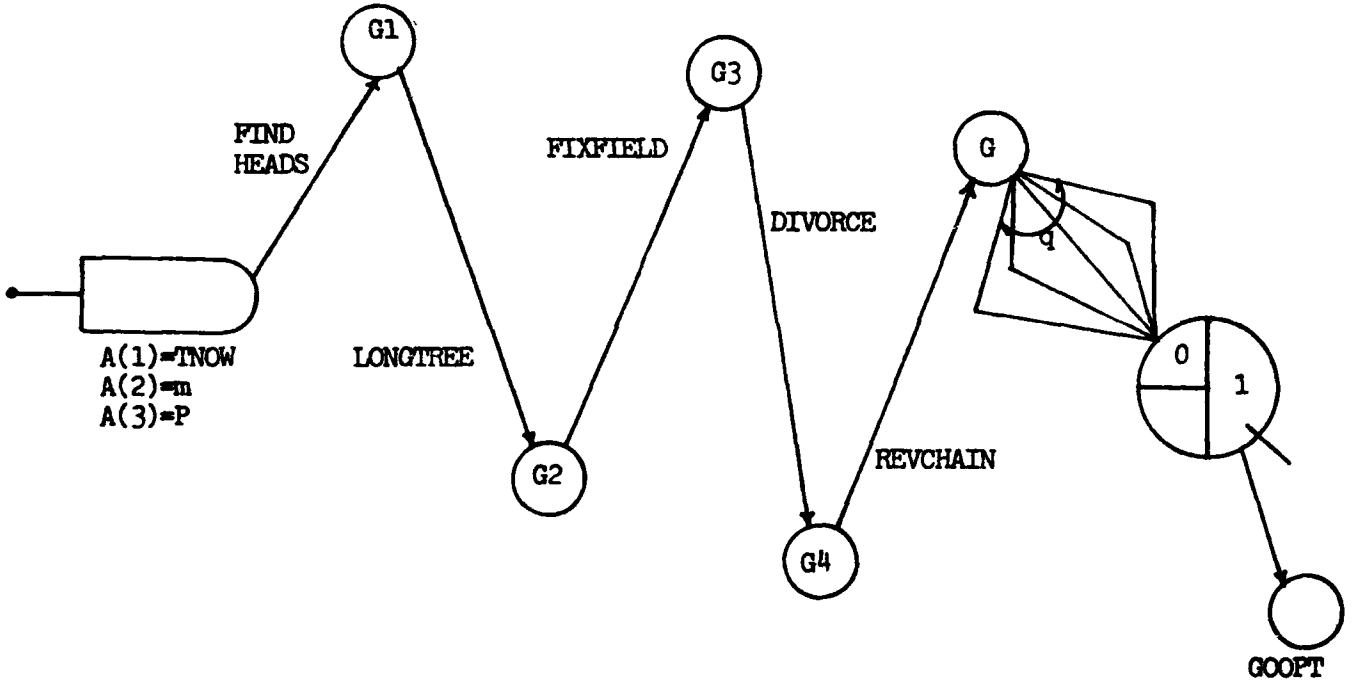

1
1
n
1
0.
A(2)=U(1)
0.
0
1
1
PROCESS
A(2)=1,2,3,4
DUIP
A(2)=5
SELECT
A(2)=6
JOIN
A(2)=7
PROJECT
DIVIDE
A(2)=8
PROCESS
1
0.
T1
X(11)LTn
X(11)=
X(11)+1
X(11)=n
X(11)=0
GOSPLIT
PROCESS(1)
1

TREE

The second LEVEL II diagram represents the second optimization module, SPLITUP. The model of SPLITUP basically consists of five service activities, each corresponding to one of the actual module's five subprocedures. SPLITUP receives a single entity as input, representing the network of shared operator trees provided by TREE. The entity must first be assigned parameter values repesenting characteristics of the network. Attribute 1 (A(1)) is assigned the current clocktime. A(2), represented by m in the diagram, obtains the number of nodes in the network. Finally, A(3) s set equal to the number of root nodes in the network of shared trees.

The entity next passes through the activity FINDHEADS, which in the actual system links the root nodes of the network. The next activity encountered is LONGTREE. In Roth's logic, LONGTREE sorts the input chain of root nodes, placing the root of the tree with the greatest number of shared subtrees first, and the root of the tree with the least number of shared subtrees last. The next simulated procedure is FIXFIELD, which initializes each node's attribute field. The entity then encounters the DIVORCE activity, which separates the shared subtrees from each tree of the network. Finally, REVCHAIN is encountered. REVCHAIN reverses the order of the root nodes to permit the formerly shared subtrees to be executed before the results of these operator trees are utilized. Following REVCHAIN

processing, the entity passes through a GOON node labeled G, which splits the entity into a finite number of entities, each representing an individual tree containing no shared subtrees. These individual trees are then queued, passing on to GOON node GOOPT, and in turn providing input to the OPTIMIZE module.

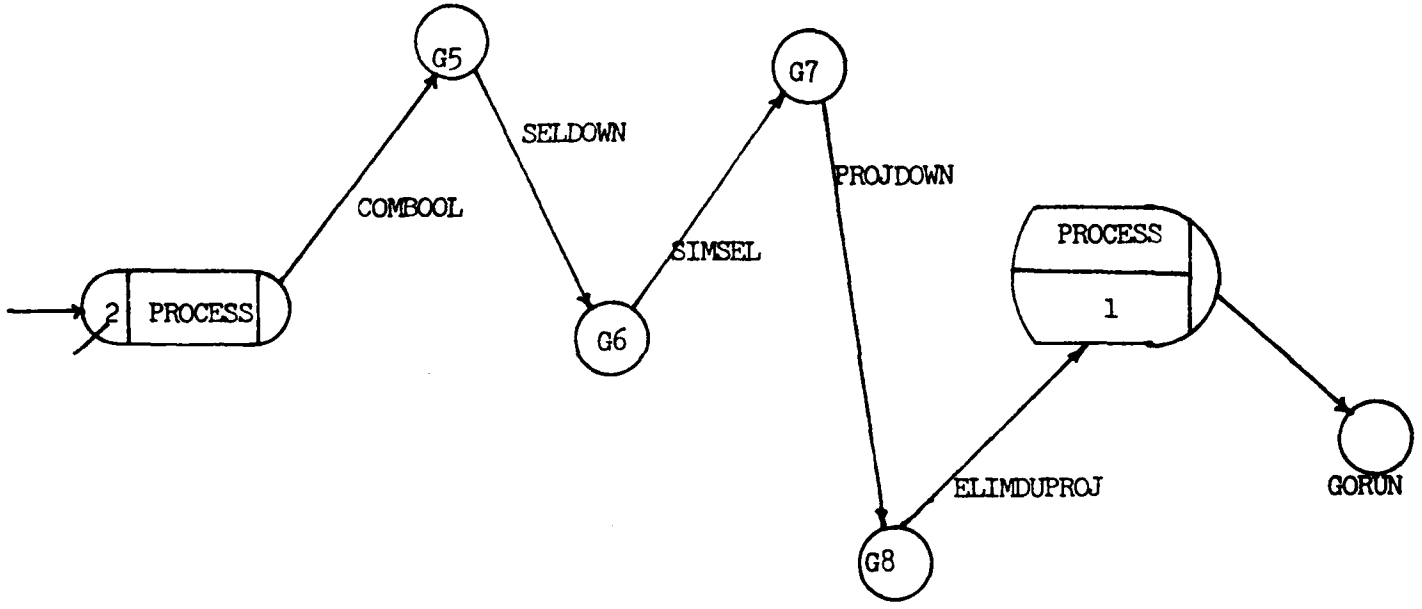

G1
FIND
HEADS
A(1)=TNOW
A(2)=m
A(3)=P
LONGTREE
G2
FIXFIELD
G3
DIVORCE
G4
REVCHAIN
G
q
0
1
GOOPT

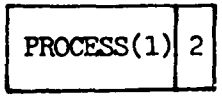
SPLITUP

The third LEVEL II diagram represents the next optimization module, OPTIMIZE. Like the TREE procedure, OPTIMIZE can only process a single entity at a time. Like SPLITUP, OPTIMIZE may be represented as a collection of service activities, each corresponding to a sub-procedure of OPTIMIZE itself.

As each entity enters OPTIMIZE, it must first obtain RESOURCE PROCESS before it may proceed with execution. The first activity encountered is COMBOOL. In the actual system, COMBOOL is responsible for converting unique data structures called "boolean subtrees" into single operators. After COMBOOL processing, the entity enters procedure SELDOWN, responsible for further optimizing the parse tree by moving SELECT operators down the operator tree. The SIMSEL activity then represents the logic which is responsible for simplifying complex SELECT operator boolean predicates. PROJDOWN then pushes PROJECT operators down the tree. Finally, duplicate PROJECT operators are eliminated by the ELIMDUPROJ algorithm.

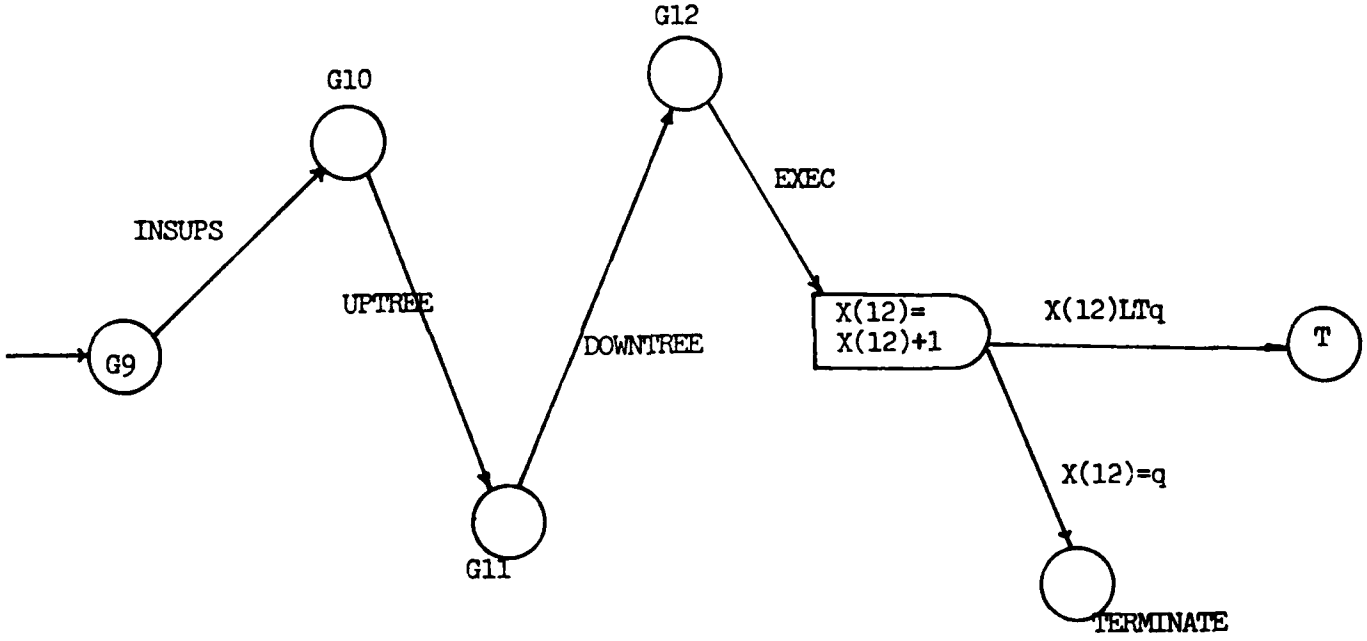
After ELIMDUPROJ has been traversed, the entity frees the PROCESS RESOURCE, permitting the subsequent tree to begin execution. The entity then goes through GOON node GORUN as input to module RUN.


G5
G7
SELDOWN
PROJDOWN
COMBOOL
SIMSEL
2
PROCESS
G6
PROCESS
1
ELIMDUPROJ
GORUN
G8


PROCESS(1)
2

OPTIMIZE

The final LEVEL II SLAM diagram depicts the RUN module of the Roth database optimization logic. The model shows that the single entity, representing the optimized operator tree produced by OPTIMIZE, first flows through activity INSUPS. The procedure INSUPS serves as a prelude to the actual algorithm which links the operator nodes. The entity then simulates processing by the activities UPTREE and DOWNTREE, two submodules which actually perform the RUN optimization algorithm. Finally, a procedure tentatively called EXEC is simulated. EXEC is responsible for executing the procedure calls created by DOWNTREE. Each time an entity completes EXEC processing, SLAM variable XX(12) is incremented. When the value of XX(12) reaches q, the number of trees output by OPTIMIZE, a single entity exits the system at terminal node TERM, representing the result of the command file being returned to the user.


G12
G10
EXEC
INSUPS
UPTREE
DOWNTREE
G9
X(12)=
X(12)+1
X(12)LTq
T
X(12)=q
G11
TERMINATE

101

RUN

APPENDIX B

BENCHMARK QUERIES

OVERVIEW

In order to measure the effectiveness of the optimization techniques employed by the Roth database logic, a set of benchmark queries, along with a set of test relations must be created. These queries and relations should be designed specifically to verify the Roth optimization techniques; i.e., to determine whether the optimization modules are successfully satisfying their objectives.

The scenario forming a basis for the benchmark queries was chosen from a paper by P. A. V. Hall which documents relational database research performed at the IBM UK Scientific Centre at Peterlee, England (Ref. 5). The scenario deals with automating the functions of a library using a relational database. The appropriate information required to support this library is stored in eleven specific relations, each of which is pictured in Table I.

QUERIES

The first benchmark command file is designed to exercise the SPLITUP logic, and actually consists of three queries which utilize shared subtrees.

```
(Q1) JOIN ACQ, LON WHERE ACQNO = ACQNO GIVING T1
     JOIN T1, BRW WHERE BRWNO = BRWNO GIVING T2
     SELECT ALL FROM T2 WHERE PRICE > 10.00 GIVING T3
     JOIN T3, STS WHERE STAT = STAT GIVING T4
     SELECT ALL FROM T4 WHERE (STAT = A AND PRICE > 10.00)
            GIVING T5
     PROJECT T5 OVER TITL, PRICE, NUMB GIVING RESULT

     JOIN ACQ, LON WHERE ACQNO = ACQNO GIVING T1
     JOIN T1, BRW WHERE BRWNO = BRWNO GIVING T2
     PROJECT T2 OVER ACQNO GIVING RESULT

     JOIN ACQ, LON WHERE ACQNO = ACQNO GIVING T1
     JOIN T1, BRW WHERE BRWNO = BRWNO GIVING T2
     SELECT ALL FROM T2 WHERE PRICE > 10.00 GIVING T3
     PROJECT T3 OVER ACQNO GIVING RESULT
```

Query 2 is designed to test the SELDOWN and PROJDOWN algorithms and consists solely of SELECT and PROJECT operators.

```
(Q2) PROJECT ACQ OVER ACQNO, AUTH, TITL, PUBL,YEAR, PRICE
            GIVING T1
     PROJECT T1 OVER ACQNO, AUTH, TITL, PUBL, YEAR GIVING T2
     SELECT ALL FROM T2 WHERE (PUBL = MCGRAW HILL) GIVING S1
     PROJECT S1 OVER ACQNO, AUTH, TITL, PUBL GIVING T3
```

```
PROJECT T3 OVER ACQNO, AUTH, TITL GIVING T4
PROJECT T4 OVER ACQNO, AUTH GIVING T5
SELECT ALL FROM T5 WHERE (ACQNO < 100) GIVING S2
PROJECT S2 OVER ACQNO GIVING RESULT
```

Query 3 also tests the SELDOWN and PROJDOWN algorithms, this time by naturally placing the SELECT and PROJECT operators at the bottom of the operator tree.

```
(Q3) SELECT ALL FROM ACQ WHERE (AUTH = HAWTHORNE) GIVING T1
     PROJECT T1 OVER ACQNO GIVING T2
     JOIN T2, LON WHERE ACQNO = ACQNO GIVING T3
     JOIN T3, BRW WHERE BRWNO = BRWNO GIVING RESULT
```

Query 5 tests the COMBOOL algorithm employed by the RUN module of the Roth logic. COMBOOL works on the principle that improved efficiency can be obtained by transforming "boolean subtrees" into single operators which read storage-resident relations only once instead of multiple times. Query 5, when directly implemented, provides an operator tree identical to the one appearing in the Roth thesis (Ref. 17, Figure 12).

```
(Q4)  SELECT ALL FROM ACQ WHERE ACQNO < 200 GIVING T1
      SELECT ALL FROM ACQ WHERE ACQNO > 500 GIVING T2
```

```
UNION T1, T2 GIVING T3
SELECT ALL FROM T3 WHERE AUTH = HAWTHORNE GIVING T4
SELECT ALL FROM ACQ WHERE (ACQNO < 50 AND ACQNO > 650)
       GIVING T5
INTERSECT T4, T5 GIVING RESULT
```

Within the EXECUTE procedure, which serves as a driver during the optimization processing, a copy of the optimized operator tree is printed to the terminal using the PRINTTREE procedure. An interesting test of execution time efficiency would be to measure Query 5 from beginning of execution through completion of the RUN module, and then, using the PRINTTREE output, to measure the same processing interval using the optimized version of the same query.

```
(Q5) UNION LON, LTD GIVING T1
     PROJECT HIST OVER ACQNO, BRWNO, DATOUT GIVING T2
     INTERSECT T1, T2 GIVING T3 DIFFERENCE T3, LON GIVING T4
     PRODUCT T4, BRW GIVING T5
     SELECT ALL FROM T5 WHERE BRWNO = BRWNO GIVING T6
     PROJECT T6 OVER ACQNO, DATOUT,BRNAM GIVING T7
     JOIN T7, HIST WHERE ACQNO = ACQNO GIVING T8
     PROJECT T8 OVER ACQNO, DATOUT, DATIN GIVING RESULT
```

RELATION	COMPONENTS						
	1	2	3	4	5	6	7
ACQ	ACQNO	AUTH	TITL	PUBL	YEAR	PRICE	CODE
NACQ	ACQNO	AUTH	TITL	PUBL	YEAR	PRICE	CODE
LACQ	ACQNO	AUTH	TITL	PUBL	YEAR	PRICE	CODE
PACQ	ACQNO	AUTH	TITL	PUBL	YEAR	PRICE	CODE
DDC	CODE	SUBJ					
BRW	BRWNO	BRWNAM	ADD	STAT			
STS	STAT	NUMB	PERD				
LON	ACQNO	BRWNO	DATOUT				
LTD	ACQNO	BRWNO	DATOUT				
RTD	ACQNO	DATIN					
HIST	ACQNO	BRWNO	DATOUT	DATIN			

Table I. Test Relations of the Library Data Base

APPENDIX C

CONSTRUCTING THE MONITOR SYSTEM

OVERVIEW

The Roth database system is written using the UCSD PASCAL language. Because of its length, however, the entire system could not be placed in a single source file. As a result, the code had to be segmented using the UCSD PASCAL segmentation feature. Each segment is individually compiled with the compiled segments then pieced together using the LIBRARIAN utility. Finally, the resulting library is linked together using the system LINKER, with the external assembly subroutine copied into the COMMON Unit where it was declared. A description of this process follows:

COMPILATION

Each segment, along with the COMMON Unit, must be individually compiled. It is imperative that the compiler directive (*$S+*) appear as the first line of code in each segment to place the compiler in swapping mode, in turn eliminating the danger of exceeding system resources. The COMMON Unit must be compiled first, so that it may be placed into the system library to be used during the subsequent compilation of the remaining segments.

LIBRARIAN

As the name implies, the LIBRARIAN is a system utility which is used to create a library. During the creation of the monitor system, the LIBRARIAN is used in two instances.

Once the COMMON unit has been compiled and placed in its own file (COMMON.CODE), it must be added to the existing system library so it is accessible during the compilation of the remaining segments. Appendix A of the Rodgers thesis (Ref. 19) outlines this procedure. After the system library is modified to include the newly compiled COMMON Unit, each remaining segment of Roth source code must be recompiled and placed in its own .CODE file.

BUILDING THE SYSTEM

After each segment has been recompiled using the new system library, LIBRARIAN must once again be used to build the segmented Roth system. For the purposes of this example, it is assumed that a segmented system .CODE file, called LIBRY.CODE, is already available, thus requiring that the existing segments be replaced with the newly compiled .CODE files. The sequence is as follows:

The user types an "X" at the system level.

The system responds with:

EXECUTE WHAT CODE FILE --->

The user enters "LIBRARY".

The system responds :

OUTPUT CODE FILE --->

At the point, the user needs to enter the name of the file which will contain the new library. For our example, the user enters LIBRY.CODE.

The system then prompts:

LINK CODE FILE --->

The user is now being requested to provide the name of the existing library; i. e., the library which needs to be modified. In our example, the link file is the same as the output file, so the user enters LIBRY.CODE.

The system then presents a library map which identifies what currently exists in each segment of the link code file. A typical example of the existing Roth system would appear as follows:

```
0-              0 4-              0 8-              0 12-INVENTOR    1888
1-DB         8140 5-              0 9-              0 13-EXECUTE    12848
2-PASCALIO   1824 6-              0 10-COMMON     936 14-TREE         9132
3-DECOPS     2092 7-              0 11-DEFINE    5382 15-RUN          8936
```

The user's task is to replace those segments existing in the current file with the newly compiled segments which were recompiled using the modified COMMON. Segments 2 and 3 of this example contain PASCAL library system segments which were not compiled using COMMON. For this reason, the first step is to merely copy these two segments into the output code file. The system prompt is:

Segment # to link and <space>, N)ew file, Q)uit, A)bort

The user responds:

2 (space)

The system prompts:

Seg to link into?

The user responds:

2 (space)

A second library map now appears on the screen, reflecting the fact that PASCALIO has been copied into the output code file. The same procedure is repeated for segment 3, DECOPS. Again the system prompts:

```
Segment # to link and <space>, N)ew file, Q)uit, A)bort
```

The user now responds:

```
N
```

The system prompts:

```
Link Code File?
```

The user is requested to enter the name of the file from which the replacement segment is to be taken. In our example, we are attempting to replace the existing segment 1, DB, with the revised segment which resides in file MAIN.CODE on Logical Unit 4. Thus, the user enters:

```
#4:MAIN.CODE
```

The system again prompts:

```
Segment # to link and <space>, N)ew file, Q)uit, A)bort
```

The user wishes to place the new code in segment 1, so he responds:

1 (space)

The system responds:

Seg to Link Into?

The user replies:

1 (space)

The library maps on the screen are now updated. The map of the output file reflects that segment 1, DB, has now been entered into the output code file. The system prompt once again appears:

Segment # to link and <space>, N)ew file, Q)uit, A)bort

The user next needs to place the revised COMMON segment into the output code file. The user responds:

N

The system prompts:

Link Code File?

Assuming that the revised COMMON file, called COMMON.CODE, resides on Logical Unit 5, the user types:

#5:COMMON.CODE

The system then prompts:

Segment # to link and <space>, N)ew, Q)uit, A)bort

The user replies:

10 (space)

The system prompts:

Seg to link into?

The user responds:

10 (space)

The library map displaying the output link file reflects that COMMON is entered into segment 10 of the new library.

This procedure is continued for segments 11 through

15. After replacing segment 15, the system once again prompts:

Segment # to link and <space>, N)ew, Q)uit, A)bort

The user now enters:

Q

The system replies:

notice?

The user enters a carriage return.

The system has now been reconstructed using the LIBRARIAN utility, and must now be processed through the LINKER before being executed. A description of the LIBRARIAN intrinsics may be found in Section 4.2 of the UCSD PASCAL Version II.0 Manual (Ref. 19).

LINKER

The linker serves two functions during the creation of the Roth executable system. First, it links the newly constructed PASCAL library which consists of the segments containing the Roth code. Second, it permits the assembly file CLOCKREAD to be copied into the system so that it may

be used during execution. The result of the linking process is the Roth database system executable .CODE file. The sequence is as follows:

At the system level, the user enters "L" to execute the Linker utility.

The system responds with:

```
Linking....


Linker[II.0]
Host File?
```

The user is now requested to enter the name of the file which contains the Roth segmented code. Drawing from the example used in the preceeding section, the user enters:

```
#5:LIBRY
```

The system respons with:

```
Opening #5:LIBRY.CODE
Lib File?
```

The user is now requested to indicate if any library

files exist which need to be copied into the executable system code file. In order to monitor the Roth system, this technique is used to make the external assembly file available for use. Assuming that the procedure CLOCKREAD has been assembled and placed in file CLOCK.CODE on Logical Unit 5, the user enters:

```
#5:CLOCK.CODE
```

The system responds:

```
Opening #5:CLOCK.CODE
Lib File?
```

The user enters a carriage return, indicating no more library files exist. The system prompts:

```
Map Name?
```

If the user wants a link map, he may enter a file name into which the map will be written. If the user desires, he may enter "PRINTER:", in which case the map will be written to the printer. If no map is requested, the user enters a carriage return.

The system replies with the following response:

```
Reading DB
Reading COMMON
Reading PASCALIO
Reading DECOPS
Reading CLOCKREA
Output File?
```

The user is now requested to enter the name of the file which will contain the executable code. In our example, the user enters:

```
#5:OP.CODE
```

The system responds:

```
Linking COMMON #10
   Copying Proc CLOCK
Linking DEFINE #11
Linking INVENTOR #12
Linking EXECUTE #13
Linking TREE #14
Linking RUN #15
Linking DB #1
```

The Linking function has now been completed. A

detailed description of the Linker utility appears in Section 1.8 of the UCSD PASCAL Version II.0 Manual (Ref. 19).

The executable version of the Roth logic, including the assembled copy of the external procedure CLOCKREAD now resides in file OP.CODE.

APPENDIX D

PROGRAM ANALYZE

```
(*-------------------------------------------------------------------
|              DATE: 8 OCT 82                                       |
|           VERSION: 1                                              |
|                                                                   |
|              NAME: ANALYZE                                        |
|        MODULE NUM: N/A                                            |
|          FUNCTION: The function of this offline program is to     |
|                    read the data contained in disk file           |
|                    MONFIL.TEXT and convert it to total monitoring |
|                    time. The finalized output is then written to  |
|                    disk file ANALFIL.TEXT.                        |
|             INPUTS: None                                          |
|            OUTPUTS: None                                          |
|      GBL VAR USED: None                                           |
|     GBL VAR CHNGD: None                                           |
|      GBL TBL USED: None                                           |
|     GBL TBL CHNGD: None                                           |
|        FILES READ: Disk file   MONFIL.TEXT                        |
|     FILES WRITTEN: Disk file   ANALFIL.TEXT                       |
|    MODULES CALLED: None                                           |
|   CALLING MODULES: None                                           |
|                                                                   |
|                                                                   |
|              AUTHOR:    Capt Gary L. Snyder                       |
|                         GCS - 82D                                 |
|-------------------------------------------------------------------*)
```

```
PROGRAM ANALYZE;
CONST
        ANALSIZE = 20;
        OVHEAD = 4.200;
        OFLOHEAD = 2.275E-2;
        HALFBUFF = 32767;
TYPE
        ANALRCRD = RECORD
            CLCKTIME : INTEGER;
            OVFLCOUNT : INTEGER;
            FNCTION : INTEGER;
                    END;
        ARRA = ARRAY[1..ANALSIZE] OF ANALRCRD;
VAR
        CNT,INCR,ARRACNT : INTEGER;
        M,A : INTERACTIVE;
```

```
        ANALARRA : ARRA;
        FINALVAL : INTEGER[20];
        TOTOVHED : REAL;
        OVFLTOT : INTEGER;
BEGIN

(*

READ EXISTING DATA OFF FILE MONFIL.TEXT
     AND CREATE DATA ARRAY ANALARRA

*)

RESET(M,'#5:MONFIL.TEXT');
WRITELN('   PROGRAM ANALYZE');
WRITELN('READING MONFIL.TEXT FROM DISKETTE');
CNT := 0;

FOR INCR := 1 TO 4 DO
    BEGIN
    READLN(M);
    WRITELN('*');
    END;

WHILE NOT EOF(M) DO
    BEGIN
    CNT := CNT + 1;
    READLN(M,ANALARRA[CNT].FNCTION,
             ANALARRA[CNT].CLCKTIME,
             ANALARRA[CNT].OVFLCOUNT);
    WRITELN('*');
    END;

(*

DERIVE FINAL MONITOR TIME
       AND PLACE IN VARIABLE FINALVAL

*)

REWRITE(A,'#5:ANALFIL.TEXT');
WRITELN('WRITING TO FILE ANALFIL.TEXT');
WRITELN(A,'ROTH DATABASE MONITOR RESULTS');
WRITELN(A);
FOR INCR := 2 TO CNT-1 DO
    BEGIN
    OVFLTOT := ANALARRA[INCR].OVFLCOUNT DIV 2;
    TOTOVHED := OVHEAD + (OVFLTOT * OFLOHEAD);
    FINALVAL := HALFBUFF;
    FINALVAL := ANALARRA[INCR].OVFLCOUNT * FINALVAL;
    FINALVAL := FINALVAL + ANALARRA[INCR].CLCKTIME;
    FINALVAL := FINALVAL - ROUND(TOTOVHED);
    WRITELN(A,'     TOTAL EXECUTION TIME OF FUNCTION ',
              ANALARRA[INCR].FNCTION,' IS  ',
```

```
                FINALVAL,'  MILLISECONDS');
    WRITELN('*');
    END;
CLOSE(A,LOCK);
END. (*ANALYZE*)
```

APPENDIX E

PAPER

THE PERFORMANCE MEASUREMENT OF A RELATIONAL DATABASE SYSTEM USING MONITORING AND MODELING TECHNIQUES

Gary L. Snyder
Capt, USAF
Air Force Institute
of
Technology

ABSTRACT

An investigation was conducted intended to uncover a productive means of measuring the effectiveness of a collection of untested relational algebra query optimization techniques integrated within an existing microprocessor-resident relational database.

As a result of this research, two methods of performance measurement were proposed. A software monitor was designed, coded, and tested specifically to determine if the employed optimization methods actually decrease the

amount of processing time required to execute a given query. Additionally, a baseline simulation model was designed and presented as an alternative means of analyzing the performance of this optimization logic.

INTRODUCTION

In the mid-1970's a new kind of management information system was devised based on relational mathematics appropriately called the "relational database". While this type of database is often heralded as the information system of the future, it has also been criticized as being slow and inefficient.

In 1979, an Air Force Lieutenant named Mark Roth set out to design, code, and implement a pedagogical relational database on a commercially available microcomputer. Roth placed emphasis on the data handling efficiency of his data manipulation language by employing two data performance techniques. The first technique, inspired by Theo Haerder (Ref. 4), relates tuples of one relation to tuples of another yielding ordering and associative access by attributes to provide efficient updates.

The second technique, inspired by an article by Dr. John Miles Smith and Philip Yen-Tang Chang (Ref. 18), may be referred to as an "automatic query optimizer interface" which logically resides between a user's set of query commands and the data residing in the system. This optimization logic modifies any set of commands such that

no matter how inefficiently the original query was constructed, it would be executed using the least amount of processing time possible.

Research indicates that the Roth system is the first attempt to operationally incorporate these query optimization techniques within an actual relational database. The potential benefits and untested status of this automatic programmer suggest the purpose of this paper: investigate techniques to measure the execution time of complex relational algebra queries in an attempt to verify the correctness and merit of the optimization methods utilized.

STATEMENT OF PROBLEM

The purpose of this paper is to address performance measurement techniques applicable to database management systems and propose practical methods which will permit the performance analysis of the Roth relational database optimization modules. The Roth system is written using the UCSD PASCAL programming language and resides on the LSI-11/2 microcomputer.

OVERVIEW OF THE OPTIMIZATION LOGIC

The Roth database was designed to achieve as near optimal behavior as possible by emphasizing query optimization at the conceptual level. It was felt that relational database systems provide users with tabular

views of data and consequently highly inefficient queries are often created. The burden of efficiency should be transferred from the user to the automatic optimization interface.

The interface logic attempts to optimize a given command file in two ways. First, an operator parse tree is built with each node corresponding to one of the relational algebra commands in the file. The tree is then rearranged with the intent of decreasing the time required to perform the subsequent retrieval. Second, this partially optimized tree is analyzed in terms of temporary relations to be created. The tuples of these relations are then preordered to enhance any searching required to process the data.

The Roth optimization interface appears in the EXECUTE module of the overall data manipulation language. The interface itself consists of four PASCAL procedures designed modularly using a top-down structured approach. The TREE procedure creates the operator tree and performs syntax checking. SPLITUP then transforms this single operator tree into a network of non-shared subtrees. OPTIMIZE then exercises algorithms designed to manipulate the tree to provide a more optimally constructed structure. Finally, RUN orders the temporary relations created and performs the actual retrieval. A comparison of these procedures to the design proposed in the Smith & Chang paper (Ref. 18) points out the similarity of the two suggested automatic interfaces.

REQUIREMENTS

Because the goal of this research is to address viable means of database performance analysis, specific measurement requirements must next be discussed. Three measurement procedures have been identified to provide the information necessary to make an assessment of the optimization techniques using a set of predefined benchmark queries designed to test the automatic interface. These procedures are:

1. Measure the execution time required to process a query using the existing logic, then measure the time required to process the same query bypassing the SPLITUP and OPTIMIZE modules as well as that portion of the RUN module responsible for sort ordering.

2. If procedure 1 indicates that optimization was counter-productive for a given query, measure the execution times of the individual optimization procedures searching for specific processing bottlenecks.

3. The Coordinating Operator Constructor employed by the RUN module implements each node of the existing operator tree using a set of basic procedures which provides optimal coordination of intermediate relations(Ref. 17, p. 70). These procedures are heuristic and untested in nature. A third requirement, then, is to measure the time required to process the RUN module while

methodically altering the techniques used to sort the relations and choose various operator implementations.

Software monitoring and simulation modeling were determined to be two credible means of measuring the efficiency of the database language. Monitoring has the advantage of being easy to interpret and empirically accurate, but modeling is more flexible and may be applied to non-operational code.

PERFORMANCE MONITOR

The Roth database system uses the UCSD PASCAL segmentation feature, which permits the compilation of large source files by breaking these files into smaller sectors. The code and data associated with these sectors (called Segment Procedures) are memory resident only while there is an active invocation of that procedure. Additionally, one of these segments, called COMMON, contains all global variables and utility procedures used by the system.

In order to monitor the optimization modules, three modifications must be made to the existing system. First, a procedure must be written capable of reading some type of clock in order to maintain the amount of time expired during testing. Second, software "hooks" must be inserted into the system to perform measurements commensurate with

the established requirements. Third, interface logic must be established providing proper communications between the clock reading procedure and the PASCAL host.

The real-time clock provided with the LSI-11/2 is the KWV11-A. This programmable clock/counter features:

1. 16 bit resolution
2. external input capability
3. four programmable modes

The clock uses two system registers which permit the user to control its operations and monitor its activities.

The procedure used to manipulate the real-time clock is written at the assembly language level and is external to the PASCAL host. Initiation of this routine forces an interrupt which resets the clock immediately after loading a register with its contents.

Calling the monitor from the host logic is a straightforward task. Because the assembly procedure is set up as a UCSD PASCAL external procedure, it may be called just like any other PASCAL procedure. An individual call is identified by passing a unique integer parameter which subsequently gets stored along with the clock value associated with that call.

The remaining task in the development of the monitor is the establishment of a software interface between the external assembly procedure and the "hooks" in the host

logic. This interface resides in the COMMON unit of the segmented code and consists of a call to the external subroutine, thus providing a "stepping stone" from host to monitor. This process is necessary, because an external assembly language procedure may only be called from the segment which declares it, in this case the COMMON Unit.

MODELING THE OPTIMIZATION LOGIC

While monitoring the performance of the Roth optimization modules is straightforward, it does carry with it one notable drawback - the code being monitored must be operational. It is not feasible that software hooks be placed in code that does not run. This is a significant issue when addressing the Roth database code because much of the RUN module has not yet been designed and due to resource constraints complex queries can not yet be processed. This limitation to monitoring makes evident one of the advantages to an alternate means of performance measurement. Simulation modeling of performance can evaluate design alone and does not require the existence of operational code.

The optimization modules of the Roth logic could be modeled using a high order simulation language in order to provide insight into the merit of their execution. As with any modeling effort, the process may be broken into six logical steps. The task of modeling the Roth query optimization logic may be addressed in terms of these six

steps:

1. PURPOSE. The purpose of a model of the Roth optimization logic is to provide an accurate representation of data flow beginning with the initial execution of a command file through the completion of the execution of the RUN module. Each entity flowing through the system represents a relational algebra command, a multi-command query, an operator tree, or a network of trees depending on the specific application and location within the system, with attributes assigned to these entities characterizing their complexity, type, and anomalies. By modifying these parameters along with the structure of the network, potential logic bottlenecks and areas requiring improvement can be identified.

2. SYSTEM ENVIRONMENT. One of the keys to a successful, meaningful model is is clearly defining exactly what needs to be represented. A model of the Roth optimization logic is specifically confined to the four PASCAL procedures TREE, SPLITUP, OPTIMIZE, and RUN. It is noteworthy that the top-down, structured design of the database permits an unambiguous interpretation of model boundaries.

3. LEVELS OF MODELING DETAIL. Just as code is designed in a top-down manner, so should the levels of detail of the Roth model. Accordingly, the first level of detail provides a representation which is an

overview of the entire optimization interface. The second level model is an expansion of this overview. Models could subsequently provide detail down to the fifth or sixth level, in turn offering great insight into the performance of the optimization techniques.

4. SYSTEM PERFORMANCE MEASURES. The next step in the modeling process is the establishment of system performance parameters; i.e., what values should be used to accurately portray the Roth system processing times, what modifications should be made to these parameters to correctly reflect different query operating characteristics, and what statistics should be used to evaluate the outcome of these modifications?

5. DEFINE ALTERNATIVES, EXPERIMENT, AND IMPLEMENT. The final two steps in the modeling process are to analyze the results of the simulation effort and attempt to detect possible weaknesses in the optimization logic which, if corrected, could further decrease the amount of execution required to perform a given user query. Having uncovered these potential deficiencies in the system, either parametric or structural changes to the model can be made, and the model can be executed again, revealing if these revisions are beneficial. Based on the observations provided by the modifications to the model, permanent design and implementation changes can be made to the Roth system which will improve the processing efficiency of the data retrieval function.

To date, simulation models of the Roth database optimization logic have been designed through the second level of detail using the Simulation Language for Alternative Modeling (SLAM).

SUMMARY

The objective of this paper was to present a practical method of measuring the efficiency of a set of relational algebra query optimization techniques integrated within the data manipulation language of a pedagogical relational database. Research indicated that not one, but two methods could be used to perform this measurement. Monitoring the logic would clearly display the amount of time required by individual modules to process a set of queries designed to test the system's capabilities. As an alternative to monitoring, modeling the system would provide the capability of evaluating performance even before system implementation.

A performance monitor was developed using a combination of UCSD PASCAL and assembly level programming designed to measure the execution time of the optimization modules in question. It is noteworthy that use of this software tool is equally applicable to any UCSD PASCAL program implemented on the LSI-11/2 Microcomputer. A model of this logic was also initiated, using the SLAM simulation language. It was determined that effective modeling of the system should be approached in a hierarchical manner,

beginning with a LEVEL I overview of the modules to be simulated. Subsequent models could then be developed, each with increased detail which would eventually lead to an experimental indication of the merit of the optimization techniques.

VITA

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An investigation was conducted to provide a productive means of measuring the effectiveness of a collection of untested relational algebra query optimization techniques which are integrated within an existing microprocessor resident relational database.

As a result of this research, two methods of performance measurement were proposed. A software monitor was designed, coded, and tested specifically to

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determine if the employed optimization methods actually decrease the amount of processing time required to execute a given query. Additionally, a baseline simulation model was designed and presented as an alternative means of analyzing the performance of this optimization logic.